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博士論文

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Using Games and Simulations to Overcome Two Obstacles that Block the Introduction of CCPM to PM Society and Validate its Effectiveness

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摘　要

自 1997 年起，限制理論(TOC)關鍵鏈專案管理(CCPM)方法已獲得了相當可觀的關注，已有數以百計導入 CCPM 成功的案例，在專案管理環境達成高度可靠的準時達交和縮短專案完成時間。但是，CCPM 導入專案管理環境仍存在兩大障礙，第一個是實務界從事專案管理者表示：對於 Goldratt 宣稱專案管理方法只要做一些簡單的改變就能夠顯著改善專案準時達交和專案完成時間缺乏信心。第二個是學術界的一些學者聲稱：CCPM 並非新知識且對於專案管理知識體系(PMBOK)無實質的貢獻。在本研究中，首先利用專案管理遊戲克服第一個障礙。接著，排除不良的人類行為後，比較研究 CCPM 和計劃評核術/要徑法(PERT/CPM)克服第二個障礙。結果顯示：(1) 專案的管理方法是造成專案準時達交和縮短專案完成時間的根本原因，且改變專案管理方法能夠顯著改善專案準時達交和專案完成時間。(2) 根據專案平均完成時間，CCPM 未顯著優於 PERT/CPM，但是根據專案規劃交期的可靠度，CCPM 優於 PERT/CPM，這是由於 CCPM 的規劃方法改變，因此比 PERT/CPM 規劃方法產生較合理且可靠的專案規劃。

關鍵字：專案管理、關鍵鏈專案管理、限制理論、計劃評核術/要徑法

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Abstract

Since 1997, the Critical Chain Project Management method (CCPM) has received considerable attention. Hundreds of successful CCPM cases have achieved highly reliable on-time delivery (OTD) with short project lead-time (PLT) in multi-project environments. However, two obstacles have remained, blocking the introduction of CCPM to project management (PM) society. The first has been addressed by PM practitioners, who have been less than confident that OTD and PLT can be significantly improved by simply changing the way to manage multi-projects. The second is from academia: some scholars have claimed that the ideas of CCPM are not new and are of no substantial contribution to PMBOK. In this study, we first used multi-project management games to overcome the first obstacle. A comparative study of CCPM and PERT/CPM planning methods, excluding bad human behaviors, was then conducted to overcome the second obstacle. Results show that: (1) the "mode of managing multi-projects" was the root cause, and changing the mode of managing multi-project could significantly improve OTD and PLT; (2) in terms of mean project time, CCPM is not significantly better than PERT/CPM. However, in terms of plan reliability, CCPM achieves higher than PERT and CPM. This is due to a CCPM logistical change that generates a more reasonable and reliable project plan than do the PERT/CPM methods.

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

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除了真摯的由衷感謝，依然是感謝。

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1. Introduction

Since Goldratt first published the Critical Chain book in 1997 (Goldratt 1997a), proposing the Critical Chain Project Management method (CCPM), the CCPM has received a lot of attention in the project management literature and has recently emerged as one of the most popular methods of project management in a multi-project environment. In the past 15 years, many project management practitioners and researchers have written books (Newbord 1998, 2008, Leach 2004 and Yuji 2010) and conducted research to enhance and spread CCPM knowledge (Steyn 2000, 2002, Rand 2000, Herrolen and Leus 2001, 2002, Elmaghraby, Herroelen and Leus 2003, Cohen, Mandelbaum and Shtub 2004, Ashtiani 2007, Jacob and Mendenhall 2008, Long and Ohsato 2007, 2008, Liu 2008, Rezaie 2009 and Cui 2010), developed software systems (Realization 2011, Prochain 2011) to support CCPM implementation, and created implementation strategy and tactics to guide practitioners in how to implement CCPM (Goldratt 2009).

CCPM method achieves highly reliable on-time delivery (OTD) and short project lead-time (PLT) in a multi-project environment mainly because it focuses on changing the way to manage multi-projects, efficiently using the safety time embedded in tasks through two changes: logistical change (planning aggressive task times with 50 % buffers, staggering the release of projects, and determining priorities with buffer management) and changing bad human behaviors (no bad multi-tasking, no exhibition of student syndrome, and no practicing of Parkinson’s Law). Although related literature has reported hundreds of successful cases achieving highly reliable OTD with short PLT in a multi-project environment (Realization 2011, Goldratt Marketing Group 2011), the introduction of CCPM to project management society still encounters two obstacles. The first is from project management practitioners, who have been less than confident that OTD and PLT, in a multi-project environment, can be significantly improved by simply changing the way to manage multi-projects. The second is from academia: some scholars have criticized the approach as offering nothing new.

Concerning the first obstacle, our interviews with local managers revealed that few agreed that the mode of managing multi-projects is the root cause of poor OTD and long PLT. The interviews were conducted in three-hour public workshops[1] attended by more than three hundred people. The majority of the participants were project managers, resources managers, and engineers. The polling question was: why is it difficult to achieve high OTD in

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[1] During the year of 2009, four workshops (January, 17th, March 14th, May 9th and June 13th) were conducted on the campus of National Chiao-Tung University, Hsinchu, Taiwan. The workshop title is: “Project the TOC way.”

multi-project management? We asked them to not just write the reasons they believe in, but also what they think others believe in. Ninety percent of their responses can be summarized as excessive task time variability (or uncertainty). Such as resources and the time available for projects are often inadequate, and tough situation becomes dire when exacerbated by severe competition in the market place. Clients and management are often slow to make decisions, delivery from suppliers is sometimes delayed, and information is not always shared in a timely manner. Moreover, project scope/specifications change and often creep. Even when problems arise, support is not necessarily forthcoming (from management or from other project stakeholders) without delay. In spite of these difficulties, project members work very hard, with a strong sense of responsibility and urgency, and are even willing to work around clock to comply with all kinds of expectations from stakeholders. Looking carefully into these uncertainty problems, it has become obvious that they do not originate within the project, but rather exist outside the project. Therefore, project members often believe that they can do little to overcome these problems even with CCPM.

In light of the above results, it is not surprising that reducing uncertainty thus has become the focus of improvement efforts, with programs such as PDM and Six Sigma becoming the norm. Unfortunately, the second polling question (if they have adopted PDM and Six Sigma programs, was OTD improved significantly?) in three-hour public workshops[1] found that for eighty percents of participants, OTD remained a major issue. Only twenty percents of the participants indicated that their OTD improved, and only through long-term effort.

Theoretically, it is not difficult to achieve highly reliable OTD in multi-project management. First, an accepted Project Evaluation and Review Technique (PERT) or Critical Path Management (CPM) network and its estimated project lead time (PLT) should be determined for each project. Since uncertainty exists, this estimated PLT should have a sufficient safety time to handle uncertainty; if not, it will be difficult to meet the deadline (Goldratt 1997b). The greater the uncertainty, the bigger the safety embedded in the task's time estimates. Second, the starting and ending times of each project should be scheduled according to the required completion date and resource limitations. If the required completion date can be achieved, then the project is confirmed. If the required completion date cannot be met due to capacity loading, the project will be given a new completion date. If the new completion date is accepted, planning is complete. If not, negotiation is initiated or the project

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is simply lost. When planning is complete, project execution begins. In most multi-project environments, to better utilize human resources, most employees are not dedicated to a single project, but must multi-task. They are organized in resource groups according to their skills, and each group performs certain types of tasks for several projects. The responsibility of these teams is to turn task time estimates into commitments. In addition to resources managers, project managers are also in charge of the project. Their responsibility is to make sure that the project is completed according to the original commitments. In the multi-project environment, projects are usually managed in a matrix structure. The progress of each project is reported periodically, and task priorities are shuffled according to urgency. Recovery plans for projects falling behind schedule are discussed and executed as necessary.

As stated above, the mode of planning and controlling multiple projects to achieve high OTD is obvious. If excessive uncertainty is the main challenge in OTD, as claimed by the managers interviewed in this study, and improvement programs for reducing uncertainty are also initiated, OTD should be significantly improved. However, the reality is that it is not improved (or improved slowly) (Standish Group 2007).

So what is the true root cause to poor OTD in multi-project management? Although Goldratt claims these problems (originating outside the projects) do not appear to be the root cause of poor OTD and long PLT in multi-project management; rather, the mode of managing multi-projects does. Specifically, four major causes related to the mode of project planning and execution will significantly affect OTD and project lead time, which are: (1) Unrealistic planning (over-promise), meaning that most key resources work across projects in a multi-project management, but poor planning fails to consider resource contentions across projects. This makes the plan unrealistic and leads to missed commitments and long project lead times; (2) A lack of clear working priorities, meaning that engineers will work on the wrong priority project in a multi-project management due to a lack of clear priorities. Working on the wrong priorities causes an interruption in the critical chain, which in turn causes a cascading effect in other tasks and ultimately leads to missed commitments and long project lead times; (3) Bad-multi-tasking, meaning that project managers in multi-project environments will release a project as soon as possible because they fear that projects will not finish on time. Releasing projects too early causes too many projects to be executed simultaneously (resources competition), which means that many resources will suffer from bad-multi-tasking. Extensive bad-multi-tasking drastically increases the lead time of both tasks and projects, which further leads to missed commitments and long project lead times.

Bad-multi-tasking also cause, in the down-stream departments, overloads follows by under loads, which creates a tendency to release more work into the system so that people will always have something to work on, which increases bad-multi-tasking, a vicious cycle. (4) Masking and misusing the safety time. People who do the tasks used to add safety time by inflating the time estimate for individual tasks. However, inflating the time estimates, in turn, leads to Parkinson's Law (not reporting on early finishes and work expands to fill the available capacity) and student syndrome. These effects cause the safety to be misused and masked. Misusing (or wasting) the safety time leads to missing the commitments. Consequently, OTD improvement programs should first focus on improving the mode of project planning and execution instead of reducing task time variability.

We realized unless it is experienced by managers themselves, we could not convince them that these problems (originating outside the projects or uncertainty) do not appear to be the root cause of poor OTD and long PLT in multi-project management; rather, the mode of managing multi-projects does. Their lack of confidence would linger. Continually seeking and trying new management methods or can do little mentality, eventually becomes the norm. Because of the difficulty in overcoming this obstacle through the collection and analysis of data obtained from directly in the field, we invited experienced project managers, resources managers, and engineers to participate in an experiment with a series of multi-project management games. Game 1 was designed to reveal how teams manage the multi-project game with no problems outside of the project. Results were collected to identify the root cause of poor OTD, and served as a baseline to make comparisons with the other games. Games 2 and 3 were designed to gather data to support the notion that "mode of managing multi-projects" was the root cause and to validate that changing the mode of managing multi-projects (CCPM) could significantly improve OTD and PLT. Such measures include reasonable and reliable project plans (more efficient use of safety time embedded in each task), reductions in bad multi-tasking, prioritizing or working on the right priority (with a buffer management system), changing work behaviors (such as those related to student syndrome or Parkinson's Law**)**. This is the first objective of the thesis.

Concerning the critics from academia, two major criticisms include the shortcomings and lack of novel ideas in CCPM. Concerning the first critic, one of the most significant shortcomings in CCPM claimed by them is the lack of mathematical analysis, specifically, in buffer sizing determination (Ashtiani 2007, Liu 2008, Long and Ohsato 2008 and Rezaie 2009), critical chain identification (Long and Ohsato 2007, Cui 2010 and Zhen Yu Zhao 2010), and priority control (Cohen, Mandelbaum and Shtub 2004). The results of newly developed methods tested for validity show that the proposed methods yield schedules that are more reliable in duration estimation and priority control than the schedules produced by the original CCPM method. By answering this critic, Goldratt (1997, 2008) and Steyn (2000, 2002) emphasize that due to uncertainty and unavailability of accurate data on task duration, optimizing buffer size, critical chain schedule, and priority control is a myth. They proposed that buffer management is the key to managing uncertainty. However, from an academic research viewpoint, these research efforts enhance the theory of the CCPM method.

Concerning the second critic, Duncan (1999) and Trietsch (2005) have argued that although CCPM presents some good ideas as new insights, these ideas are not new. They have claimed that the project management literature has thoroughly documented changing bad human behaviors, such as reducing bad multi-tasking. They also doubts whether it has much to offer when applying the PMBOK (2004) concepts properly. Steyn (2000, 2002), referring to Drucker (1985), mentioned that a large new method is not new knowledge. Innovation is a new perception. It is putting together things that have been around for a long time in a way that no one has thought of putting together before. His study concluded that CCPM puts together concepts that have not been combined in the same way before, and is therefore considered an innovation. Steyn's study presents that CCPM achieves highly reliable OTD (On Time delivery) and short PLT (Project Lead Time) in a multi-project environment mainly because it makes good use of safety time imbedded in tasks by implementing two changes: logistical change (plan aggressive task times with 50% buffers, stagger the release of projects, determine priorities with buffer management) and bad human behavior change (no bad-multi-tasking, no student syndrome and no Parkinson's Law).

Yuji (2010) in his book claims by applying logistical changing aligned with performance measurement change and buffer management creates a situation in which good behaviors become more desirable. For example, giving people "aggressive but possible" task duration and not judging the ability of people to meet their time estimates reduces the student syndrome and Parkinson's Law. People who are given "aggressive but possible" task duration cannot accept additional tasks at the local level and senior management cannot easily add additional tasks to them because they do not have their own safety time. Multi-tasking reduces in both situations. Logistical change staggers each project as late as possible with a synchronization buffer and schedules the non-critical chain as late as possible with a feeding buffer. Both reduce multi-tasking behavior. Switching a resource between tasks only when a project buffer erodes to the extent that it poses a risk of delaying a project further avoids multi-tasking, as well as setting priorities only according to the degree the task consumes its project (or feeding) buffer. Buffer management of CCPM determines the priority of a task by examining its affect on project completion. Bendoly and Swink (2007) also supported that lack of timely information affects the behaviors of project managers in ways that do not directly focus on work objectives, but that affect performance.

Steyn also indicated that the assumptions regarding bad human behaviors are not critical to CCPM validity, unlike logistical change. However, Steyn did not adequately support that assumption. Leach (1999) also indicated that although applying the CCPM increases OTD and reduces PLT successfully, it is still difficult to determine to what extent the CCPM or the mere emphasis on logistical change contributes to success.

Although Goldratt (1997b, 2003) with his simulation results pointed out that mere emphasis on logistical change CCPM outperforms with no logistical change in terms of OTD and short PLT (Table 1.1).

Table 1.1 Compare the simulator results

Days until project completion		**Chance to complete**		
		10%	**50%**	**90%**
CCPM	**Project 1**	80	95	115
	Project 2	140	160	180
	Project 3	170	190	210
With no logistical change	**Project 1**	95	111	131
	Project 2	151	171	201
	Project 3	178	198	222

By carefully examining Goldratt’s simulation model, which was designed according to the scheduling rule in which the first task of each project path starts only at the planned start time (Figure 1.1), even if it can be started early (as late as possible). This rule favors CCPM because the starting time of the first task of each project path planned by CCPM will be started earlier than those planned with no logistical change.

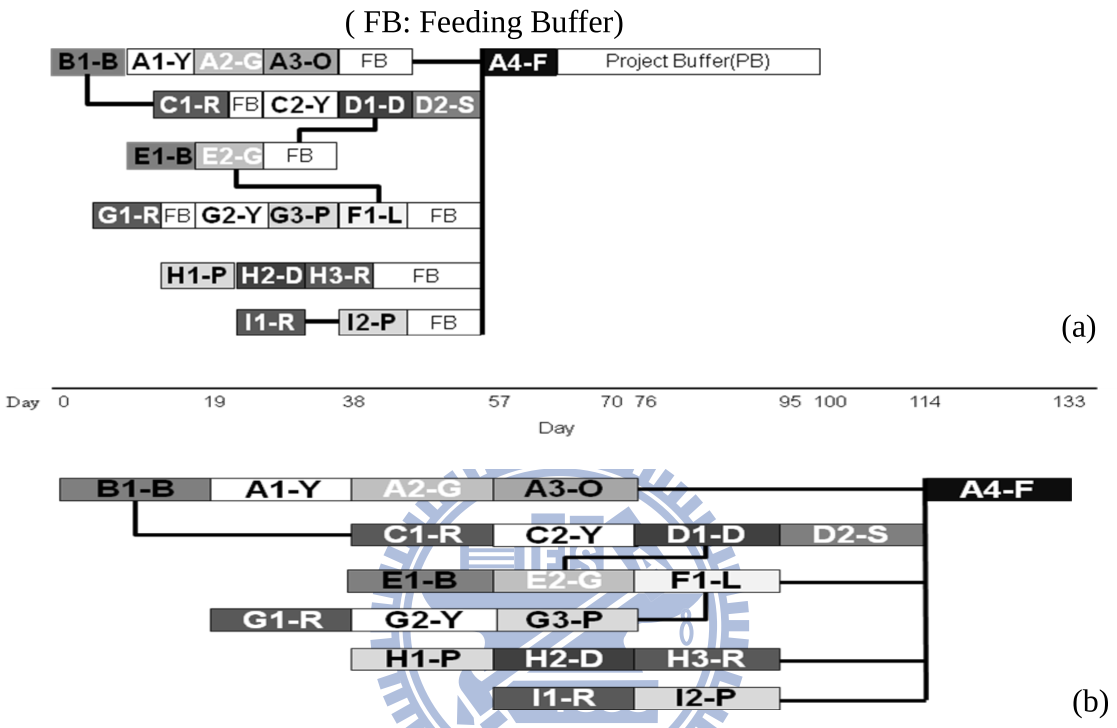

(FB: Feeding Buffer)

Figure 1.1 (a) CCPM Single Project Plan, (b) Single Project Plan with no logistical change

Does the mere emphasis on logistical change contribute to the success of project reduction and OTD improvement? To answer this question, a multi-project management simulation experiment was designed to conduct a comparative study of the critical chain and PERT planning method, without bad human behaviors. Because the planning (project time estimation) and execution methods affect the success of PLT reduction and OTD, we first compared the CCPM method with the PERT method to evaluate the planning results of the two methods regarding the same project networks and uncertainties. Second, we simulated both plans to evaluate OTD performance under different scheduling rules. This is the second objective of the thesis.

2. Literature reviews

2.1 Fundamental of CCPM

Critical Chain Project Management (CCPM) is a methodology for planning, executing and managing projects in single and multi-project environments. Critical Chain Project Management was developed by Dr Eli Goldratt and was first introduced to the market in his Theory of Constraints book “Critical Chain” in 1997(Goldratt 1997a). It was developed in response to many projects being dogged by poor performance manifested in longer than expected durations, frequently missed deadlines, increased costs in excess of budget, and substantially less deliverables than originally promised.

The CCPM achieves highly reliable OTD and short PLT in a multi-project environment mainly because it makes good use of safety time imbedded in tasks by implementing three changes: logistical change, human behavior change and buffer management.

Logistical change

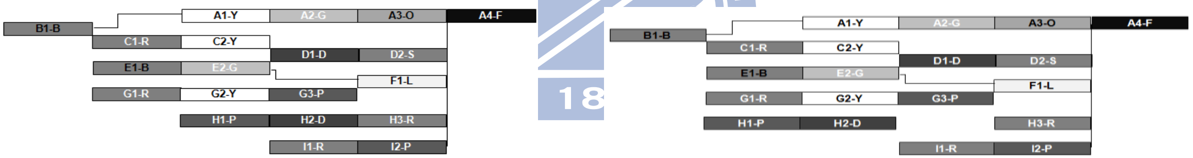
Logistical changes were performed by applying CCPM, Critical chain planning and buffering method. The theory behind the CCPM is that safety time embedded at the task level prolongs the project without providing sufficient safety for project completion, and tends to promote negative human behavior and bad multi-tasking. The greater the degree of uncertainty, the greater the safety imbedded in the time estimates for each task, which leads to more severe negative human behavior and bad multi-tasking. In the vast majority of project environments, safety represents at least half of the time estimate. Shifting safety from the tasks (this gives “aggressive but possible or most likely” 50/50 task duration) to the end of their respective task sequences (paths) places safety in a position where it should be, and requires much less safety than the sum of safeties removed from the tasks. To encourage resources working on “aggressive but possible” task time requires no longer judging resources by their ability to meet their time estimates, which further requires a performance measurement change. In other words, resource must recognize that, except for the project due date, the schedule indicates targets or expected durations rather than commitments or milestones. The CCPM method consists of two major steps: (1) Building a critical chain plan for each single project from its project network and (2) Staggering projects.

The steps involved in building critical chain plans from a project network include: (1) Lay out everything for the project network-push as late as possible, to determine where resource contention may fall. (2) De-conflict contention. (3) Identify critical chains—the

Critical Chain is defined as the longest chain [not path] of dependent tasks. In this case, 'dependent' refers to resources and resource contention across tasks/projects as well as the sequence and logical dependencies of the tasks themselves. This differs from the Critical Path Method. (4) Insert project buffer—a project buffer is inserted at the end of the project network between the last task and the completion date. Any delays on the longest chain of dependant tasks will consume some of the buffer but will leave the completion date unchanged and so protect the project. The project buffer is typically recommended to be half the size of the safety time taken out, resulting in a project that is planned to be 75% of a "traditional" project network. (5) Insert feeding buffer—everywhere a non-critical chain path or task dependency exists, requires a feeding buffer. Delays on paths of tasks feeding into the longest chain can impact the project by delaying a subsequent task on the Critical Chain. To protect against this, feeding buffers are inserted between the last task on a feeding path and the Critical Chain. The feeding buffer is typically recommended to be half the size of the safety time taken out of the feeding path. Figure 2.1 illustrates the steps of critical chain planning.

Step 1 Layout as late as possible

Step 2.1 De- conflict contention:D1-D/H2-D



Step 2.2 De- conflict contention:

A1-Y/C2-Y/G2-Y

Step 3 Identify critical chains:

B1-A1-G2-C2-D1-D2-A4

Step 4 Insert project buffer and feeding buffer (half the size of the safety time taken out from the task)

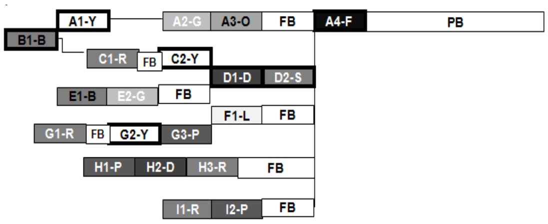
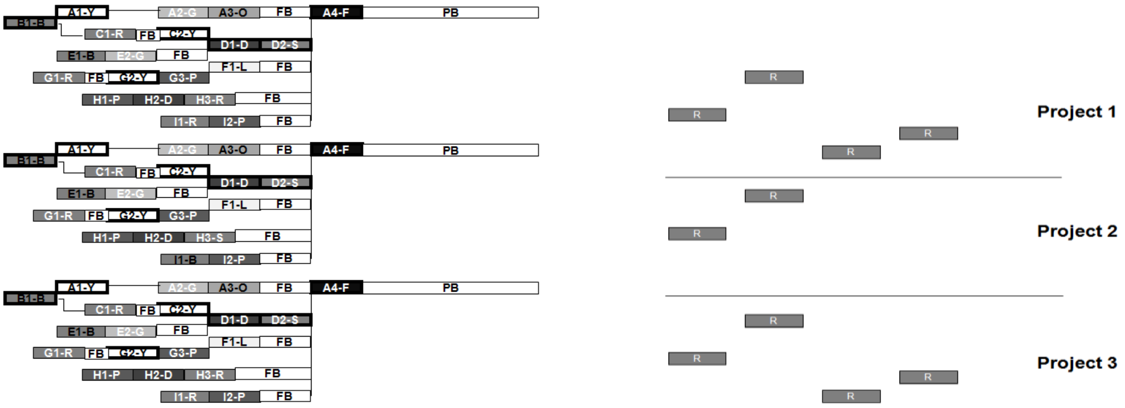


Figure 2.1 The steps of critical chain planning

The steps involved in staggering projects include: (1) Select the resource with the highest load and (2) Stagger the projects according to the highest loaded resource to determine the starting time of the first task of each project path and the project delivery date. Because time estimates are cut in half, one of the important elements in staggering projects properly is to ensure enough staggering caused by the schedule of the “highest loaded resource” (referred to as drum schedule in CCPM) to minimize peak loads on the other resources (possibly caused by bad multi-tasking again). To ensure this, a time buffer (called a synchronization buffer) was added to the schedule of the “highest loaded resource.” This time buffer also prevented any negative variability in accomplishing the drum tasks in one project from influencing the start of drum tasks in another project. The CCPM utilized up to 100% of the safety that was formerly in the drum task estimates and reallocated the safety to the synchronization buffer. Figure 2.2 shows the steps of projects staggering.

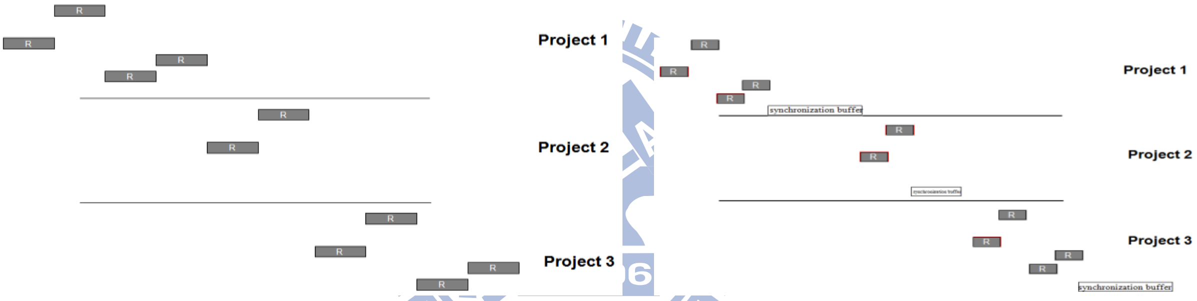
Step 1 Three similar projects before staggering

Step 2 Identify the highest loaded resource type: Red (R)



Step3 Stagger the projects according to the highest loaded resource

Step 4 Insert Synchronization buffer



Step 5 Multi-project planning result of CCPM

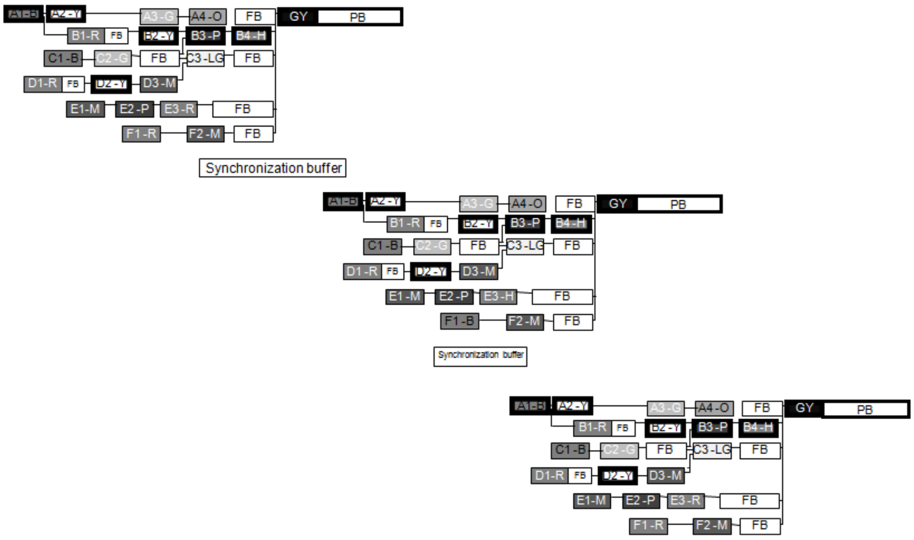


Figure 2.2 The steps of projects staggering of CCPM

Human behavior change

Uncertainty is the nature of the project task. Experience shows that safety is necessary to protect the due date and to avoid disappointing people. However, how can people work with the safety? How do people work when there is even a little safety? People may think there is still time until the due date, and be slow to start the task. Then, when they approach the deadline, they cram to make the deadline. This is the so-called student syndrome (delay the starting time to lengthen the duration time). To make matters worse, Parkinson's Law states that people will always use the given time and expand work to fill the available capacity. Both behaviors result in misusing and masking the safety time, which leads to missed commitments.

Further more, in multi-project environment, releasing projects too early causes too many projects to be executed simultaneously. This means working under pressure on more than one task at a time, making multi-tasking unavoidable. Prolific bad multi-tasking drastically increases the lead-time of tasks and projects, which leads to further missed commitments. The lack of clear priorities combined with the fear of not finishing projects on time also leads to multi-tasking.

To avoid these three bad human behaviors, CCPM advocates that logistical change, aligned with performance measurement change and buffer management, creates a situation in which good behaviors become more desirable. For example, giving people "aggressive but possible" task duration and not judging the ability of people to meet their time estimates reduces the student syndrome and Parkinson's Law. People who are given "aggressive but possible" task duration cannot accept additional tasks at the local level and senior management cannot easily add additional tasks to them because they do not have their own safety time. Multi-tasking reduces in both situations. Logistical change staggers each project as late as possible with a synchronization buffer and schedules the non-critical chain as late as possible with a feeding buffer. Both reduce multi-tasking behavior. Switching a resource between tasks only when a project buffer erodes to the extent that it poses a risk of delaying a project further avoids multi-tasking, as well as setting priorities only according to the degree the task consumes its project (or feeding) buffer. Buffer management of CCPM determines the priority of a task by examining its affect on project completion. Bendoly and Swink (2007) also supported that lack of timely information affects the behaviors of project managers in ways that do not directly focus on work objectives, but that affect performance.

Buffer Management

CCPM uses buffer management during project execution to answer two main questions: (1) Which task do task managers work on next? (2) When do project managers take actions to expedite the project? Tracking CCPM projects requires identifying when tasks start and finish, and obtaining estimates on the remaining duration for tasks in work. The reason to use remaining duration rather than estimates of completion is that humans tend to overestimate the percentage complete. When called upon to look forward and consider the work remaining to complete a task, people tend to make more accurate estimates. Remaining duration is also the actual number needed to estimate project completion, and estimating it directly avoids the assumptions necessary to convert a percent complete estimate to a remaining duration estimate.

CCPM buffer management then uses the estimates of remaining duration for incomplete tasks to calculate the impact of the task status, including the absorption of variation by feeding buffers, to determine how much of the project buffer has been used. The amount each buffer is consumed relative to project progress tells us how badly the delays are effecting our committed delivery date. If the variation throughout the project is uniform then the project should consume its project buffer at the same rate tasks are completed. The result is a project completed with the buffer fully consumed on the day it was estimated and committed. Task managers place priority on the tasks that cause the greatest amount of project buffer penetration. Project Managers determine the corrective actions necessary to ‘recover’ buffer time at points in the project where the buffer consumption is occurring faster than the project is progressing.

Buffer consumption is monitored daily by the project manager and recovery action taken where necessary Consumption of the buffer indicates a task is exceeding the ambitious time and that the task manager may need assistance. Action at the project level may be needed to recover a situation. Senior managers monitor the status of all projects and take action where necessary. At this level the priority status of all projects is reviewed periodically to monitor and address higher level program recovery. Reasons for delay are monitored and provide focus for improvement. The relevant reasons for delay are extracted to focus improvement activity. Figure 2.3 illustrates a visual buffer management method developed by Holt (2010).

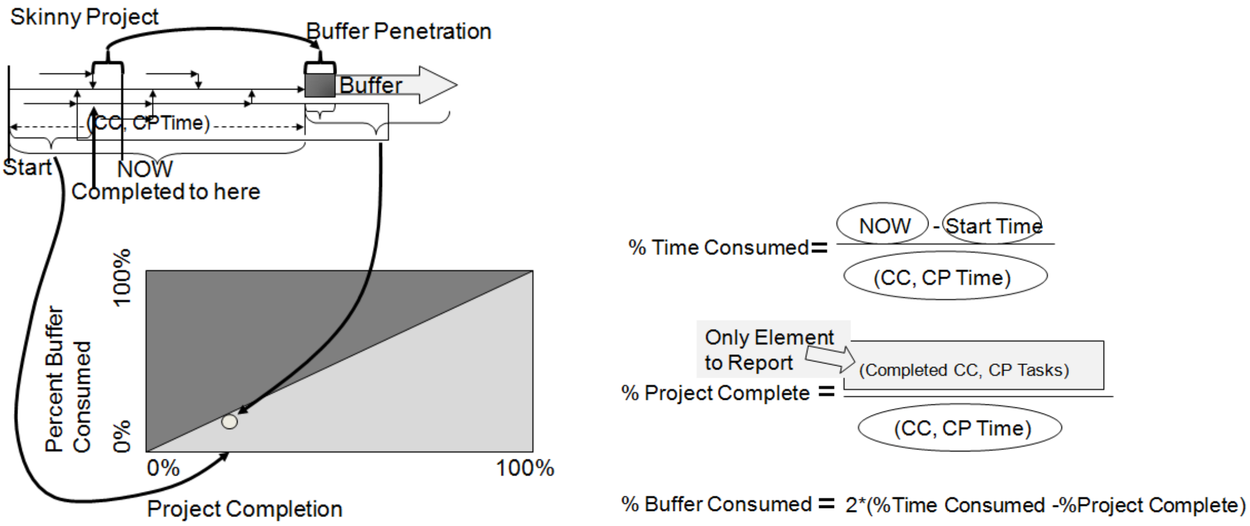


Figure 2.3 Visual Buffer management

2.2 Review of CCPM literature

In the past 15 years, many project management practitioners and researchers have written books (Newbord 1998, 2008, Leach 2004, Yuji 2010 and Goldratt School 2010) and conducted research to enhance and spread CCPM knowledge (Steyn 2000, 2002, Rand 2000, Herrolen and Leus 2001, 2002, Elmaghraby, Herroelen and Leus 2003, Cohen, Mandelbaum and Shtub 2004, Ashtiani 2007, Jacob and Mendenhall 2008, Long and Ohsato 2007, 2008, Liu 2008, Rezaie 2009 and Cui 2010), developed software systems (Realization 2011, Prochain 2011) to support CCPM implementation, and created implementation strategy and tactics to guide practitioners in how to implement CCPM (Goldratt 2008, Goldratt School 2010 and Realization 2011). The literature has also reported hundreds of successful cases achieving highly reliable on-time delivery with short project lead-time in a multi-project environment (Realization 2011, TOCICO 2011, Goldratt Marketing Group 2011).

The main distinction between CCPM and traditional project management is well reported (Newbold 1998, Leach 1999, Umble and Umble 2000, Steyn 2000). Pittman (1994) and Walker (1998) examined the single and multiple project environments (respectively) sought to expose the assumptions and practice of scheduling and controlling projects by traditional methods. Hoel and Taylor (1999) sought to provide a method (via simulation) for determining the appropriate size for the buffers required by CCPM. Ran (2000) introduced CCPM to the project management literature framing CCPM as an extension of TOC. He concluded that CCPM not only dealt with the technical aspects of project management (like PERT/CPM) but also that CCPM dealt with how senior management manages human behavior in the construction of the project network as well as the execution of the network.

Steyn (2000) followed this research with an investigation of the fundamentals of CCPM. He concluded that a major impediment to implementing CCPM is that it requires a fundamental change in the way project management is approached and that such a change is likely to meet with resistance. Lechler et al. (2005) acknowledges the clear benefits but highlights the challenge in adopting a different mindset and suggests it could explain some failures. The issues include the greater discipline of having activity times with the buffers removed and the complexity of managing multiple buffer types.

Despite this positive information, however, there are questions over whether elements of the design are original to Goldratt. Trietsch (2005) is most critical in this area goes into some detail on the elements of the approach he would attribute to others. This includes: (1) earlier reference to resource dependency 'the critical sequence' (Wiest 1964) and general awareness of the need to consider limiting resources in the network plan. It would appear resource dependency was acknowledged academically but this was not effectively incorporated in profession tools before CCPM. (2) The abolition of intermediate due dates which he links back to Schonberger (1981), among others, who was an early proponent of lean and had seen the damage that intermediate dues dates had on traditional batch manufacture. (3) Trietsch acknowledges the important contribution of feeding buffers, but again questions their originality, citing his work as earlier. He suggests project buffers naturally arise under other names as in Obrien's (1965) term 'contingency'. CCPM is inherently simple in concept, therefore, it would be surprising if the elements had not already been identified. However, even Trietsch (2005) acknowledges Goldratt's important contribution in drawing together these elements in a holistic manner as do other more critical authors (Raz et al., 2003). Duncan (1999) also criticized that although CCPM presents some good ideas as new insights, these ideas are not new. They also doubt whether it has much to offer when applying the PMBOK (2004) concepts properly.

Several authors (Raz et al. 2003, Elton and Roe 1998) also argue the approach brings more discipline but raise reservations over downplaying the traditional importance of personal project management skills. Raz et al. (2003) also suggests the industrial successes are due to the adoptions being in organizations who have poor project management implementations in the first place. However, no empirical evidence was offered and the growth in applications, and the case research reported here.

Raz et al. (2003) also argues that the software and training cost resulting from the need for a change in the organizational culture works against this approach. For example, the need to give up task time ownership, not use task due dates and avoiding multi-tasking. Again no research evidence is offered but these issues are explored in the case research that follows.

Raz et al. (2003) questions the stability of a bottleneck resource within a project environment as does Trietsch (2005). He quotes the work of Hopp and Spearman (2000) in questioning the merits of DBR over CONWIP arguing that CONWIP is less susceptible to bottleneck instability. Although this critique was not directed at CCPM the instability of the bottleneck resource in project management has more recently been acknowledged by Goldratt (2007). His original guidance (1997) was to plan projects around a ‘drum’ in the form of a resource. This has now been changed to a virtual drum resource that acknowledges any limiting resource is likely to move and the real issue in projects is not resource constraints but synchronization (2007). It is intended that this new development will be closely investigated through this research if the opportunity arises.

Several authors raise question over the sizing of buffers to comprise one third of the path duration. It needs to be acknowledged that there is no scientific bases for the buffer sizing but it is clear the size of the buffer required depends on several factors, including frequency of updates, task uncertainty and project service level. A proposal to size a buffer using a fixed as well as a variable element (Raz et al., 2003) is an interesting possibility but Goldratt advocates that even in construction where uncertainty is relatively low the generic sizing rule still holds as the buffer is a natural extension of the task time. Although this results in an inherently simple policy there are clear merits in simplicity, but undoubtedly further justification is desirable. These matters will be closely monitored in the design of the case research that follows, however, we need to determine whether the any additional complications add significant value. Raz et al. (2003) also question the validity of the assumption that tasks are routinely overestimated then wasted as well as the practicality of extracting the buffer time from the task estimates. They suggest that transferring some of the estimate to the buffer will reduce commitment or encourage further escalation of the task time estimates. Again, this claim is central to the CCPM approach and will be specifically investigated in the case research.

Concern is also raised over the use of a buffer penetration ratio for priority setting, arguing that other factors such as project value could be more important. This argument is indeed valid if it is assumed not all projects can be finished on time. Herroelen and Leus

(2001) conducted computational experiments and argued the buffer sizing can be improved by '*clever project scheduling methods such as branch and bound*'. They suggest such '*advanced project scheduling tools can be implemented as black boxes without forcing management or workers to know the technical details of the scheduling mechanism involved*'. Further work is clearly warranted here but due consideration needs to be given to the uncertain nature of the real world and the benefit of simple pragmatic solutions that work with the full engagement of management rather than the use of 'black box' logic.

Herroelen, Leus, and Demeulemeester (2001) continued much of the same argument in a later paper. Likewise, Raz, Dvir, and Barnes re-examined CCPM and concluded that project performance is often a function of the skills and capabilities of project leaders and that "some CCPM principles do make sense in certain situations" (2003). McKay and Morton (1998) as well as Pinto (1999) were concerned that CCPM might be misapplied by managers who failed to understand the underpinnings of CCPM and who attempted to adopt it without full changing their fundamental approach to the management of projects.

Answering this criticism, Steyn (2002) sought to apply TOC to a variety of other areas of project management beyond the creation and execution of project schedules. He recognized the multidisciplinary nature of project management and how it affects cash flow, stakeholder needs, and risk management. Yeo and Ning (2002) began work on integrating supply chain management with project management. Sonawane (2004) incorporated systems dynamics with CCPM to create a "modern" project management system. Similarly, Lee and Miller (2004) applied systems thinking to multiple projects along with CCPM, and Trietsch (2005) argued that CCPM is, in fact, a more holistic approach to project management than traditional methods. Goldratt (1997, 2008) emphasize that due to uncertainty and unavailability of accurate data on task duration, optimizing buffer size, critical chain schedule, and priority control is a myth. He proposed that buffer management is the key to managing uncertainty. However, from an academic research viewpoint, these research efforts enhance the theory of the CCPM method.

Cerveny, and Galup (2002) also pointed out that the strength of CCPM is in the ability it gives organizations and project managers to protect project flow from the inevitable uncertainty and variability that cannot be planned out of existence. The focus that knowledge of the constraining resource provides also ensures that appropriate and consistent criteria to prioritize projects, accelerate lead times, and ensure proper resource behavior are aligned. The

TOC/thinking process (TOC / TP) methodology of CCPM is presented as a logically derived, comprehensive, and holistic approach to achieving these desired outcomes. He believes that it provides an alternative, more complete solution for project management that can be implemented.

There are clearly many questions regarding the details underpinning the application of CCPM but the overriding consensus is that CCPM makes a significant conceptual and practical contribution. The process of improvement is ongoing, as illustrated in the S&T developments (Goldratt 2007) discussed later and, as all solutions are underpinned by assumptions it is important to expose those that may prove to be invalid in establishing the boundaries and targeting the improvement process. Trietsch (2005) advocates more scrutiny over the underlying assumptions stressing Goldratt's claim 'it works' only means the flawed assumptions are not fatal. This is indeed true and, therefore, what is needed is to identify the fatal flawed assumption first in embarking on a process of ongoing improvement. To do this, however, research needs to be closely allied to practice which is a particular concern in designing the case research that follows.

2.3 CCPM Strategy and Tactics tree

Structure of Strategy and Tactics Tree

The TOC Strategy & Tactics tree (S&T tree) developed by Goldratt (2007) is the TOC Thinking Process application for facilitating whole-company ongoing improvement. Goldratt defines strategy as simply the answer to the question "what for?" or "what is the purpose (the desired effect) of ?" Tactics are the answer to the question "How do we achieve the strategy/desired effect (using a chosen mode of operation)?" Based on these definitions, S&T entities always exist together; for different levels, S&T entities exist at each level. This means talking about S&T tree is actually talking about a structure that looks something like that shown in Figure 2.4 (Goldratt 2007). At the top are the strategy and tactics of the highest level. This study will call it the mission statement. Further down the tree addresses how to achieve the mission set out in the mission statement and goes into the functions with greater and greater detail. Each level must provide the answers to "what for" and "how."

The S&T tree is, probably, the most powerful thinking process tool and the logical structure that enables focusing. The S&T trees bring clarity to implementations by enhancing management level communications and synchronizing various departments. The trees considerably shorten the time to reach results and smooth the transition from one implementation stage to the next. They also enable introducing the detailed implementation plan of TOC solutions into the public domain.

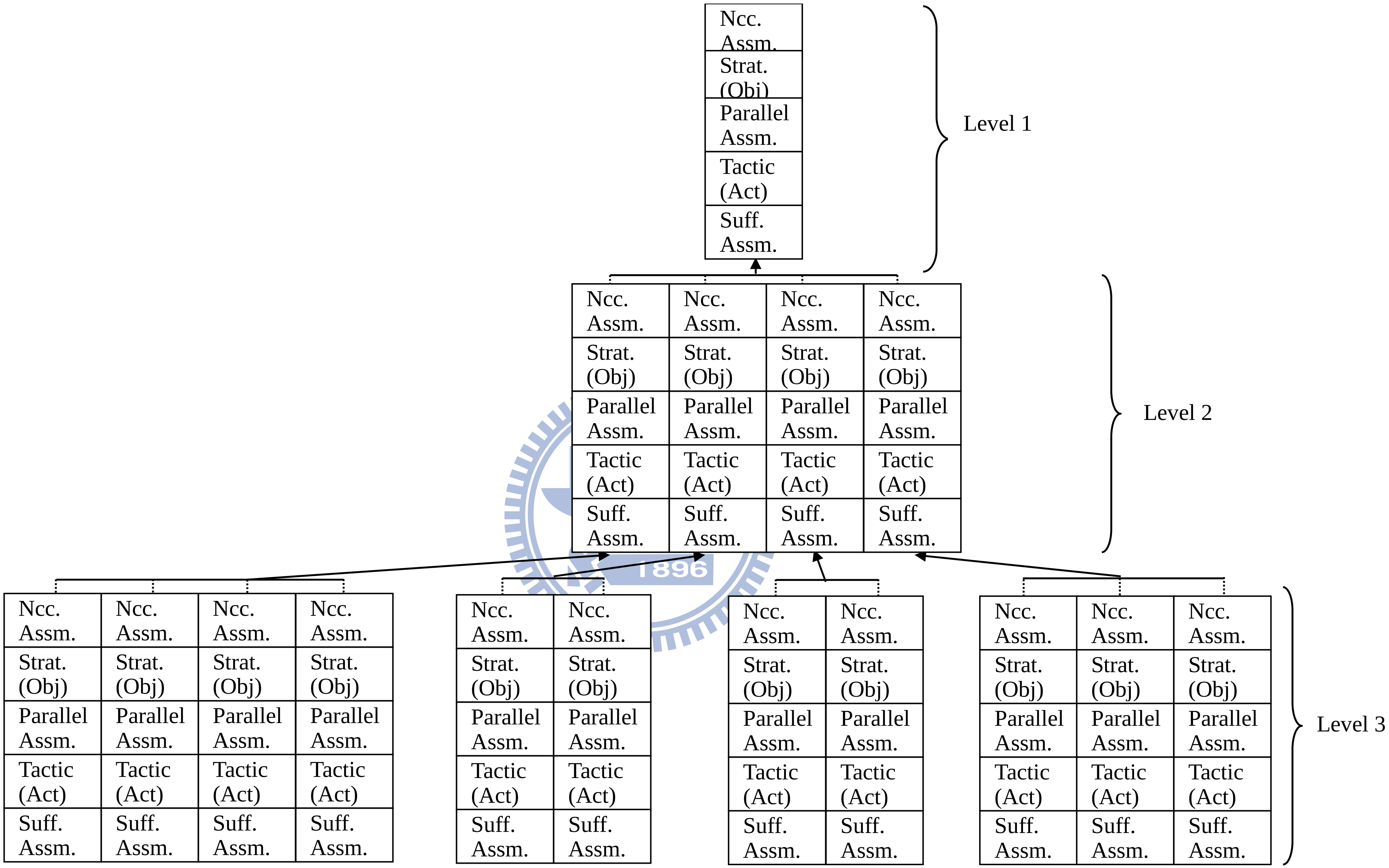


Figure 2.4 (Goldratt 2009): A complete structure of S&T tree

CCPM Strategy and Tactics tree

Despite hundreds of reported accounts of successful Theory of Constraints (TOC) Critical Chain Project Management (CCPM) implementations (Realization 2011, Goldratt Marketing Group 2011). The concern of CCPM solutions are conceptual only; even success stories lack in depth discussions on how to translate the concept into practice to reach results (how to implement CCPM). Their major concern was the lack of solid implementation steps to effect change. Goldratt acknowledged that TOC CCPM has previously not had solid implementation steps. Consequently, he developed Strategy and Tactics (S&T) trees (Barnard 2008, 2009) to provide step by step guidance for effecting change. Figure 2.5 illustrates the CCPM S&T tree developed by Goldratt (Barnard 2008, 2009). The highest level of the tree shown is the step, "Meeting project promises". Six steps in a group at level two form the necessary steps sufficient to achieve the step a level one, including "Reducing bad multi-tasking and WIP", "Full kitting", "Critical chain planning and buffing", "Managing execution", "Migrating client's disruption" and "Managing sub-contractors or subcontracted sub-projects". Going down to level three, there are four steps in a group, "Freezing", "Accelerate project completion", "Defrost mechanism" and "Releasing of new projects", that form the necessary steps to achieve the step "Reducing bad multi-tasking and WIP". The three steps, "Preparations according to priorities", "Defining preparations" and "Worried clients" are necessary for the group to achieve the step "Full Kitting". The other three steps, "Building good project plans/PERTs", "Building critical chain plans" and "Staggering project portfolio," are necessary for the group to achieve the step "Critical chain planning and buffing". Finally, the four steps, "Task completion reporting", "Task managers' role in managing execution", "Project managers' role in managing execution" and "Top management role in managing execution" are necessary for the group to achieve the step "Managing execution."

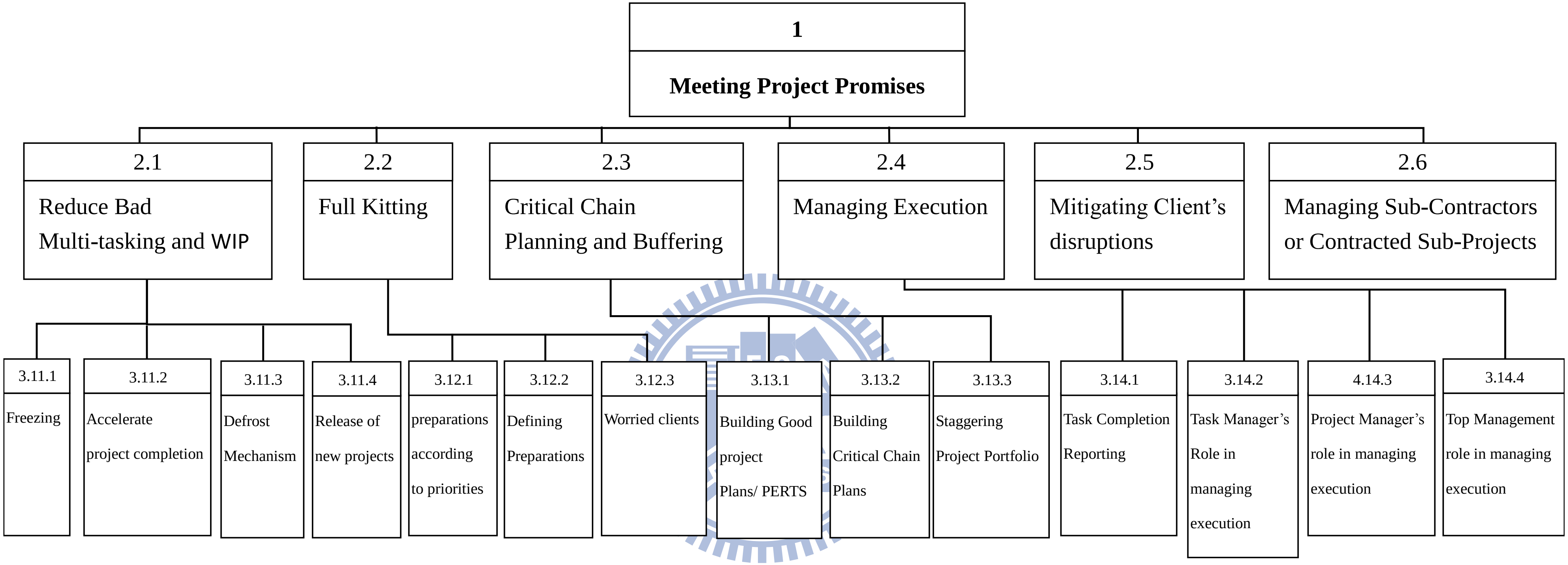
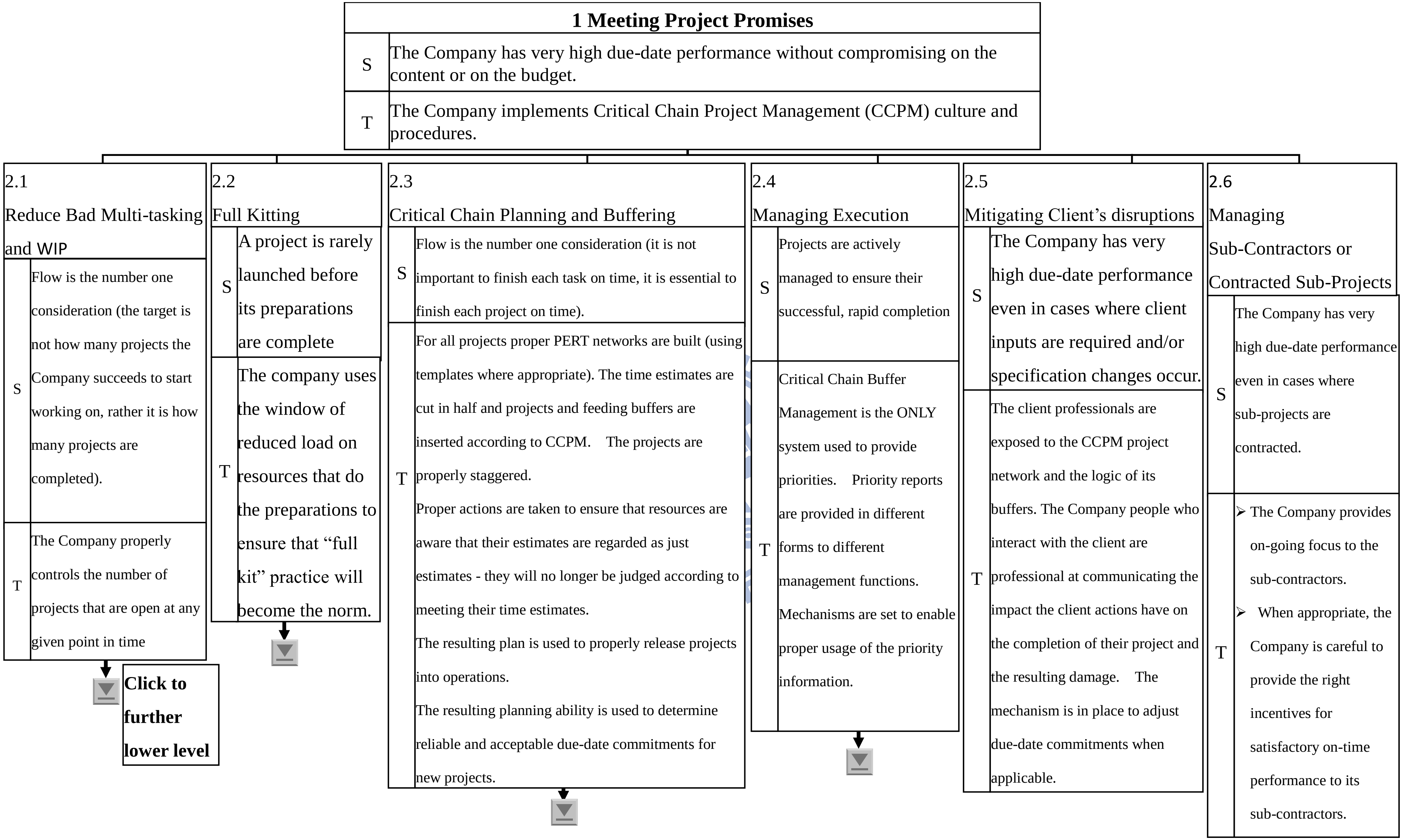


Figure 2.5 (Barnard 2008, 2009): The SDBR S&T tree

Figure 2.6a illustrates the strategic and tactic entities of level 1 and level 2. The strategy entity (what for) of level one is “The Company has very high due-date performance without compromising on the content or on the budget”, and its corresponding tactic entity (how) is “The Company implements Critical Chain Project Management (CCPM) culture and procedures”. To attain the level one objective, “The Company has very high due-date performance without compromising on the content or on the budget”, five necessary strategy entities of level two are necessary, including ” Flow is the number one consideration (the target is not how many projects the Company succeeds to start working on, rather it is how many projects are completed)”, “A project is rarely launched before its preparations are complete”, etc. Each "Strategy entity" of level two must have a corresponding “Tactic entity” which details the tactic entity, ”The Company implements Critical Chain Project Management (CCPM) culture and procedures” of level one. This includes, “The Company properly controls the number of projects that are open at any given point in time”, “The company uses the window of reduced load on resources that do the preparations to ensure that “full kit” practice will become the norm”, etc.

Click the button (shown on the bottom in Figure 2.6a) of steps 2.1, 2.2, 2.3 and 2.4 will go down their lower level. Figure 2.6b illustrates the strategy and tactic entities necessary for step 2.1. In order to attain the objective set out in step 2.1, “Reducing bad multi-tasking and WIP”, it requires four necessary strategy and tactics entities including 3.11.1 ” Freezing”, 3.11.2 “Accelerate project completion”, 3.11.3 ” Defrost mechanism” and 3.11.4 “Releasing of new projects”. Each "Strategy entity" must have a corresponding “Tactic entity” which details the tactic entity of its higher level. Successful implementation of these four steps will lead to successful implementation of step 2.1 Similarly, Figures 2.6c-2.6e show the strategy and tactics necessary to achieve the objectives set out in steps 2.2 ” Full kitting”, 2.3 “Critical chain planning and buffing” and 2.4 “Managing execution”.



1 Meeting Project Promises

S: The Company has very high due-date performance without compromising on the content or on the budget.

T: The Company implements Critical Chain Project Management (CCPM) culture and procedures.

2.1 Reduce Bad Multi-tasking and WIP

S: Flow is the number one consideration (the target is not how many projects the Company succeeds to start working on, rather it is how many projects are completed).

T: The Company properly controls the number of projects that are open at any given point in time

Click to further lower level

2.2 Full Kitting

S: A project is rarely launched before its preparations are complete

T: The company uses the window of reduced load on resources that do the preparations to ensure that "full kit" practice will become the norm.

2.3 Critical Chain Planning and Buffering

S: Flow is the number one consideration (it is not important to finish each task on time, it is essential to finish each project on time).

T: For all projects proper PERT networks are built (using templates where appropriate). The time estimates are cut in half and projects and feeding buffers are inserted according to CCPM. The projects are properly staggered.
Proper actions are taken to ensure that resources are aware that their estimates are regarded as just estimates - they will no longer be judged according to meeting their time estimates.
The resulting plan is used to properly release projects into operations.
The resulting planning ability is used to determine reliable and acceptable due-date commitments for new projects.

2.4 Managing Execution

S: Projects are actively managed to ensure their successful, rapid completion

T: Critical Chain Buffer Management is the ONLY system used to provide priorities. Priority reports are provided in different forms to different management functions. Mechanisms are set to enable proper usage of the priority information.

2.5 Mitigating Client's disruptions

S: The Company has very high due-date performance even in cases where client inputs are required and/or specification changes occur.

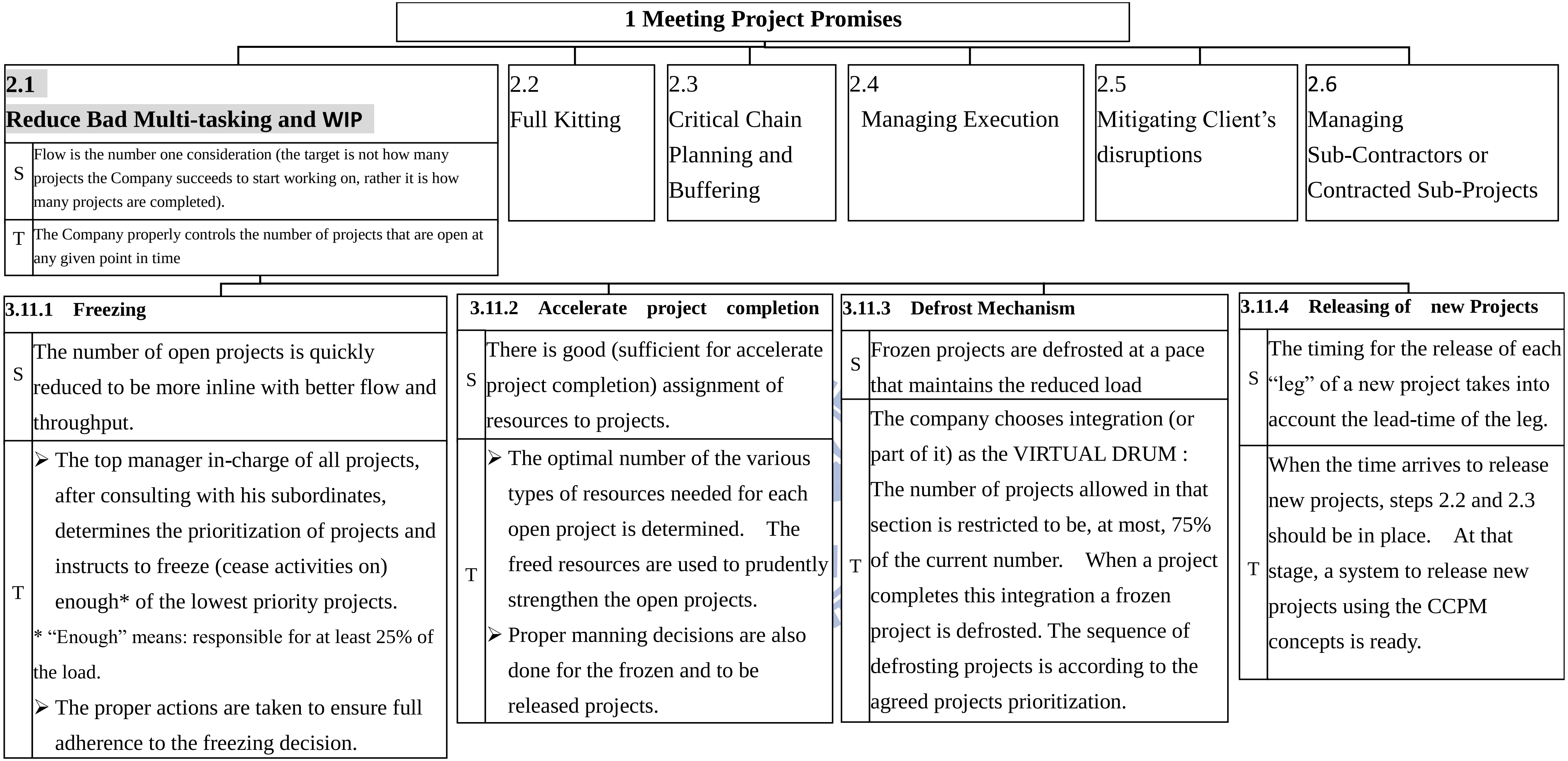
T: The client professionals are exposed to the CCPM project network and the logic of its buffers. The Company people who interact with the client are professional at communicating the impact the client actions have on the completion of their project and the resulting damage. The mechanism is in place to adjust due-date commitments when applicable.

2.6 Managing Sub-Contractors or Contracted Sub-Projects

S: The Company has very high due-date performance even in cases where sub-projects are contracted.

T:
- The Company provides on-going focus to the sub-contractors.
- When appropriate, the Company is careful to provide the right incentives for satisfactory on-time performance to its sub-contractors.

Figure 2.6a (Barnard 2008, 2009): The details of CCPM S&T tree level 1 and 2



1 Meeting Project Promises

2.1 Reduce Bad Multi-tasking and WIP

S: Flow is the number one consideration (the target is not how many projects the Company succeeds to start working on, rather it is how many projects are completed).

T: The Company properly controls the number of projects that are open at any given point in time

2.2 Full Kitting

2.3 Critical Chain Planning and Buffering

2.4 Managing Execution

2.5 Mitigating Client's disruptions

2.6 Managing Sub-Contractors or Contracted Sub-Projects

3.11.1 Freezing

S: The number of open projects is quickly reduced to be more inline with better flow and throughput.

T:

- The top manager in-charge of all projects, after consulting with his subordinates, determines the prioritization of projects and instructs to freeze (cease activities on) enough* of the lowest priority projects.

* "Enough" means: responsible for at least 25% of the load.

- The proper actions are taken to ensure full adherence to the freezing decision.

3.11.2 Accelerate project completion

S: There is good (sufficient for accelerate project completion) assignment of resources to projects.

T:

- The optimal number of the various types of resources needed for each open project is determined. The freed resources are used to prudently strengthen the open projects.
- Proper manning decisions are also done for the frozen and to be released projects.

3.11.3 Defrost Mechanism

S: Frozen projects are defrosted at a pace that maintains the reduced load

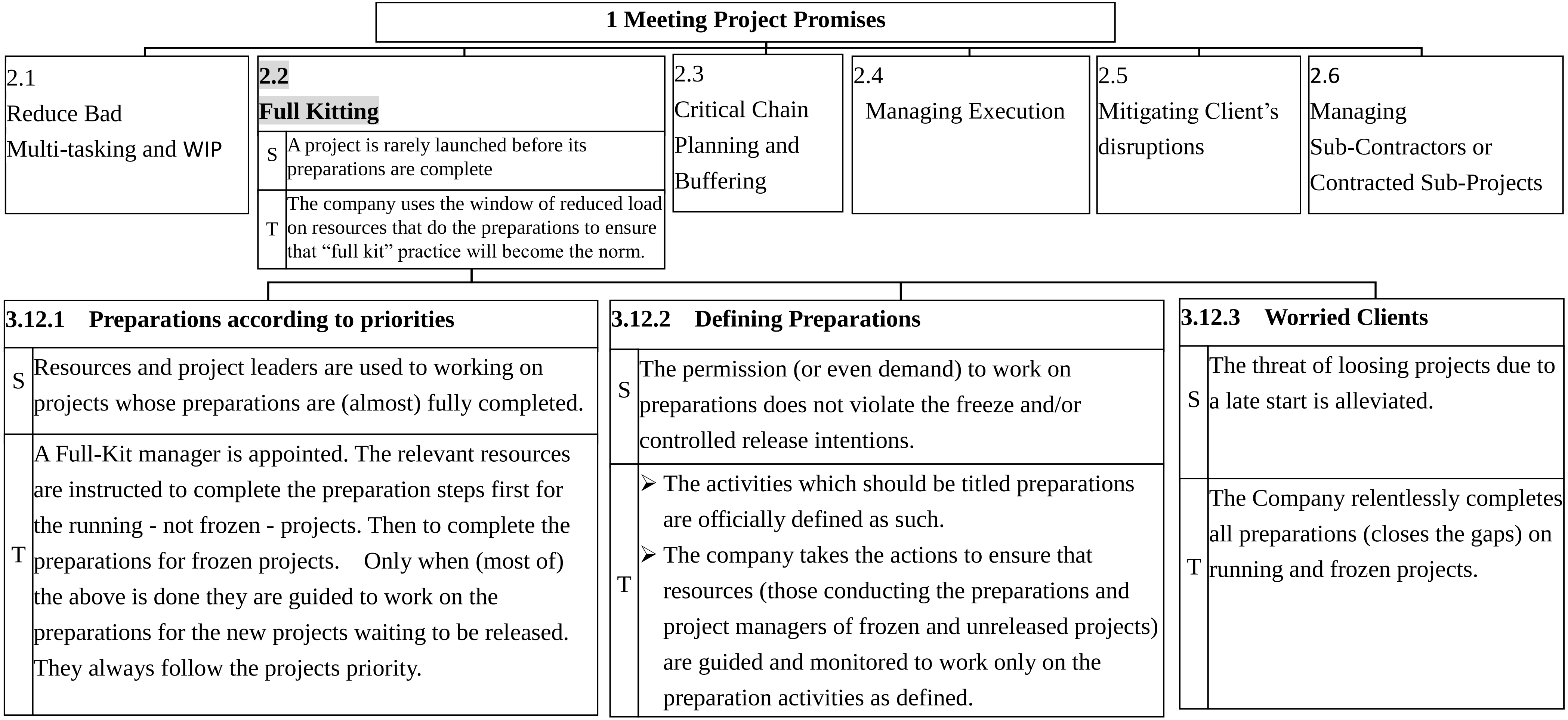
T: The company chooses integration (or part of it) as the VIRTUAL DRUM : The number of projects allowed in that section is restricted to be, at most, 75% of the current number. When a project completes this integration a frozen project is defrosted. The sequence of defrosting projects is according to the agreed projects prioritization.

3.11.4 Releasing of new Projects

S: The timing for the release of each "leg" of a new project takes into account the lead-time of the leg.

T: When the time arrives to release new projects, steps 2.2 and 2.3 should be in place. At that stage, a system to release new projects using the CCPM concepts is ready.

Figure 2.6b (Barnard 2008, 2009): The details of CCPM S&T tree level 2 and 3



1 Meeting Project Promises

2.1
Reduce Bad
Multi-tasking and WIP

2.2
Full Kitting

S: A project is rarely launched before its preparations are complete

T: The company uses the window of reduced load on resources that do the preparations to ensure that "full kit" practice will become the norm.

2.3
Critical Chain
Planning and
Buffering

2.4
Managing Execution

2.5
Mitigating Client's
disruptions

2.6
Managing
Sub-Contractors or
Contracted Sub-Projects

3.12.1 Preparations according to priorities

S: Resources and project leaders are used to working on projects whose preparations are (almost) fully completed.

T: A Full-Kit manager is appointed. The relevant resources are instructed to complete the preparation steps first for the running - not frozen - projects. Then to complete the preparations for frozen projects. Only when (most of) the above is done they are guided to work on the preparations for the new projects waiting to be released. They always follow the projects priority.

3.12.2 Defining Preparations

S: The permission (or even demand) to work on preparations does not violate the freeze and/or controlled release intentions.

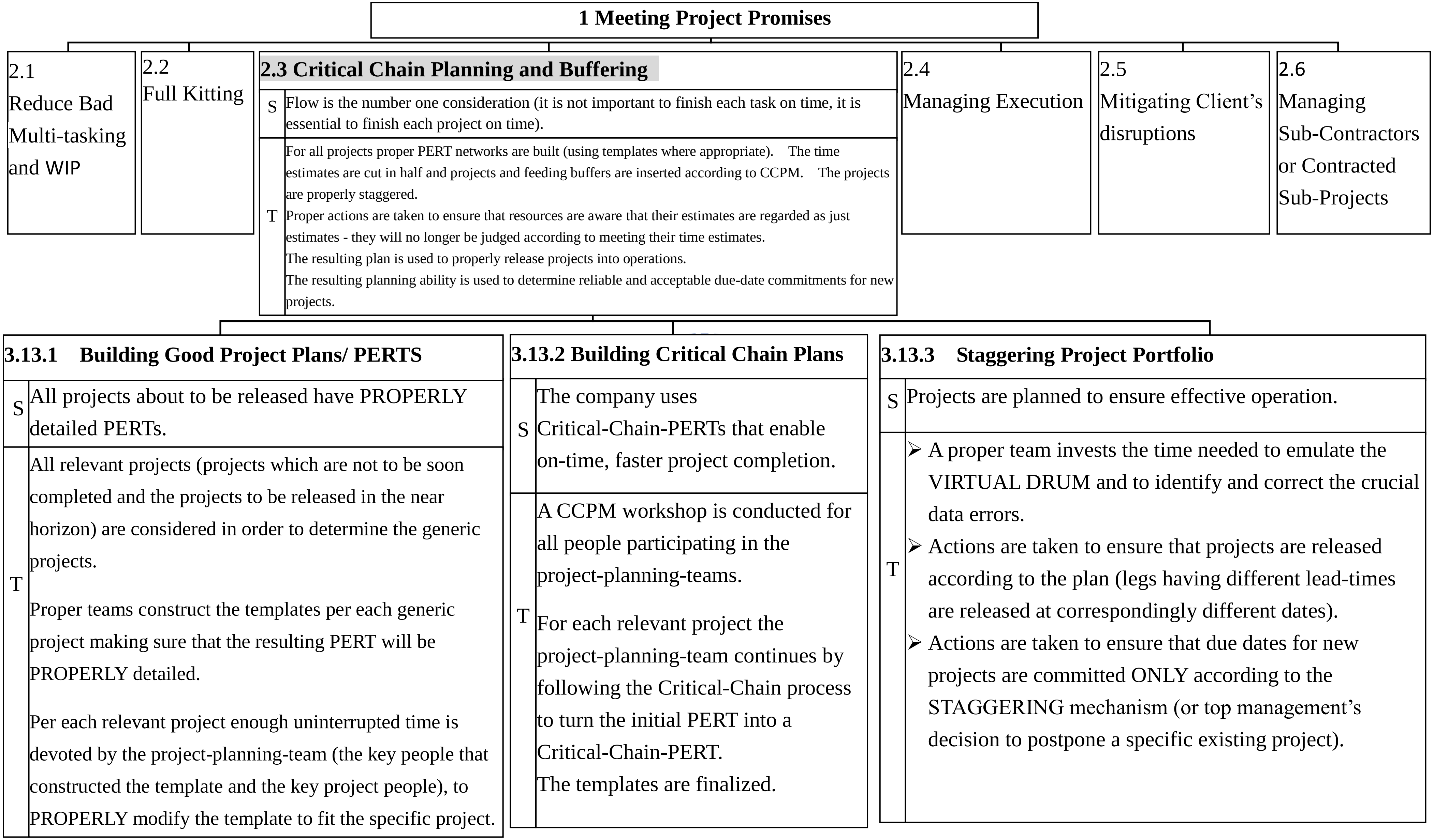
T:
- The activities which should be titled preparations are officially defined as such.
- The company takes the actions to ensure that resources (those conducting the preparations and project managers of frozen and unreleased projects) are guided and monitored to work only on the preparation activities as defined.

3.12.3 Worried Clients

S: The threat of loosing projects due to a late start is alleviated.

T: The Company relentlessly completes all preparations (closes the gaps) on running and frozen projects.

Figure 2.6c (Barnard 2008, 2009): The details of CCPM S&T tree level 2 and 3



1 Meeting Project Promises

2.1 Reduce Bad Multi-tasking and WIP

2.2 Full Kitting

2.3 Critical Chain Planning and Buffering

S Flow is the number one consideration (it is not important to finish each task on time, it is essential to finish each project on time).

T For all projects proper PERT networks are built (using templates where appropriate). The time estimates are cut in half and projects and feeding buffers are inserted according to CCPM. The projects are properly staggered.
Proper actions are taken to ensure that resources are aware that their estimates are regarded as just estimates - they will no longer be judged according to meeting their time estimates.
The resulting plan is used to properly release projects into operations.
The resulting planning ability is used to determine reliable and acceptable due-date commitments for new projects.

2.4 Managing Execution

2.5 Mitigating Client's disruptions

2.6 Managing Sub-Contractors or Contracted Sub-Projects

3.13.1 Building Good Project Plans/ PERTS

S All projects about to be released have PROPERLY detailed PERTs.

T All relevant projects (projects which are not to be soon completed and the projects to be released in the near horizon) are considered in order to determine the generic projects.

Proper teams construct the templates per each generic project making sure that the resulting PERT will be PROPERLY detailed.

Per each relevant project enough uninterrupted time is devoted by the project-planning-team (the key people that constructed the template and the key project people), to PROPERLY modify the template to fit the specific project.

3.13.2 Building Critical Chain Plans

S The company uses Critical-Chain-PERTs that enable on-time, faster project completion.

T A CCPM workshop is conducted for all people participating in the project-planning-teams.

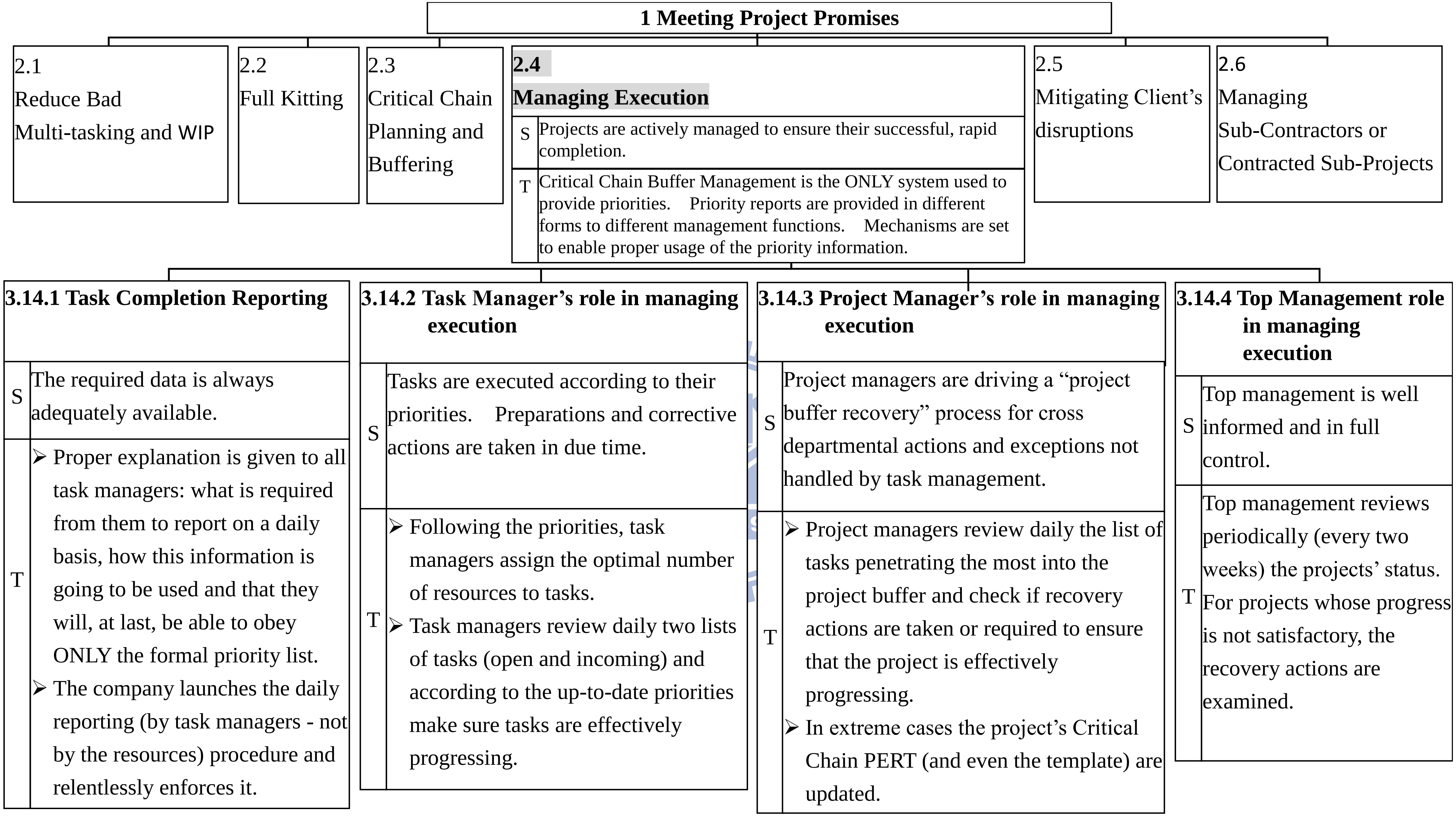
For each relevant project the project-planning-team continues by following the Critical-Chain process to turn the initial PERT into a Critical-Chain-PERT.
The templates are finalized.

3.13.3 Staggering Project Portfolio

S Projects are planned to ensure effective operation.

T
- ➢ A proper team invests the time needed to emulate the VIRTUAL DRUM and to identify and correct the crucial data errors.
- ➢ Actions are taken to ensure that projects are released according to the plan (legs having different lead-times are released at correspondingly different dates).
- ➢ Actions are taken to ensure that due dates for new projects are committed ONLY according to the STAGGERING mechanism (or top management's decision to postpone a specific existing project).

Figure 2.6d (Barnard 2008, 2009): The details of CCPM S&T tree level 2 and 3



1 Meeting Project Promises

2.1
Reduce Bad
Multi-tasking and WIP

2.2
Full Kitting

2.3
Critical Chain
Planning and
Buffering

2.4
Managing Execution

S Projects are actively managed to ensure their successful, rapid completion.

T Critical Chain Buffer Management is the ONLY system used to provide priorities. Priority reports are provided in different forms to different management functions. Mechanisms are set to enable proper usage of the priority information.

2.5
Mitigating Client's
disruptions

2.6
Managing
Sub-Contractors or
Contracted Sub-Projects

3.14.1 Task Completion Reporting

S The required data is always adequately available.

T
- Proper explanation is given to all task managers: what is required from them to report on a daily basis, how this information is going to be used and that they will, at last, be able to obey ONLY the formal priority list.
- The company launches the daily reporting (by task managers - not by the resources) procedure and relentlessly enforces it.

3.14.2 Task Manager's role in managing execution

S Tasks are executed according to their priorities. Preparations and corrective actions are taken in due time.

T
- Following the priorities, task managers assign the optimal number of resources to tasks.
- Task managers review daily two lists of tasks (open and incoming) and according to the up-to-date priorities make sure tasks are effectively progressing.

3.14.3 Project Manager's role in managing execution

S Project managers are driving a "project buffer recovery" process for cross departmental actions and exceptions not handled by task management.

T
- Project managers review daily the list of tasks penetrating the most into the project buffer and check if recovery actions are taken or required to ensure that the project is effectively progressing.
- In extreme cases the project's Critical Chain PERT (and even the template) are updated.

3.14.4 Top Management role in managing execution

S Top management is well informed and in full control.

T Top management reviews periodically (every two weeks) the projects' status. For projects whose progress is not satisfactory, the recovery actions are examined.

Figure 2.6e (Barnard 2008,2009): The details of CCPM S&T tree level 2 and 3

In addition to strategic and tactic entities, other components can be added to each step, and all can be considered as explanations: necessary assumption (explains why the given step is necessary (as part of the group) to achieve the higher step), parallel assumption (explains why the step's tactic will achieve the step's strategy) and sufficient assumption (explains why all the steps of the corresponding lower level are sufficient to attain this step). Figure 2.7 illustrates all the information necessary to form the "Reducing bad multi-tasking and WIP" step. Detailed information of each step of the CCPM S&T tree can be found in (Goldratt 2007).

2.1	**Reduce Bad Multi-Tasking & WIP**
Necessary assumptions	➢ When too many projects are executed simultaneously many resources will find themselves under pressure to work on more than one task — bad multi-tasking is unavoidable. ➢ Prolific bad multi-tasking significantly prolongs each project's lead-time.
Strategy	Flow is the number one consideration (the target is not how many projects the Company succeeds to start working on, rather it is how many projects are completed).
Parallel assumptions	➢ The statement, "the earlier we start each project, the earlier each project will be finished," is not correct for multi-project environments (not only the first elephant but also the last elephant will go through a door much faster if they go in procession). ➢ Vast experience shows that in multi-project environments, reducing the number of open projects can reduce bad multi-tasking without causing starvation of work and therefore significantly reduces the lead time of all projects — it increases the flow.
Tactic	The Company properly controls the number of projects that are open at any given point in time
Sufficiency assumption	Adjusting the amount of work is not enough. The company must also ensure that as time passes the proper amount of work will be always maintained.

Figure 2.7 (Barnard 2008, 2009): Step 2.1 of CCPM S&T tree

2.4 Successful cases of CCPM

CCPM has been successfully implemented in hundreds of organizations (Realization Technologies Inc., 2011), all of which claim that it is possible to significantly achieve highly reliable OTD with short PLT in multi-project management. For example, ABB AG, Power Technologies Division had the execution problem ‘throughput was 300 bays per year’, then by managing execution, throughput increased to 430 bays per year. And Chrysler had the execution problem ‘Cycle time for prototype builds was 10 weeks’, then by managing execution, Cycle time for prototype builds reduced to 8 weeks. The Warner Robins Air Logistics Center (WR-ALC) is changed with the repair and overhaul of C-5 transport aircraft. After an eight-month implementation period starting in 2005 and without the addition of any resources, WR-ALC returned five additional aircraft to the operational fleet by reducing the number of in-service planes from 12 to 7. The replacement value of these aircraft is $2.4 billion and does not consider nonmonetary benefits such as increased responsiveness and casualty avoidance during wartime. A Boeing initiative on the Lockheed Martin-Aero F22 Fighter Wing Assembly pilot implementation resulted in the following: “Unprecedented performance” in meeting schedules and beating budgets. Good morale (“best team and cross-shift relations ever”). Diffusion of interest in CCPM across company, divisions, and disciplines (Cerveny and Galup 2002). Summary of some successful execution management results reported by the customers of Realization Technologies Inc. is presented in Appendix A.

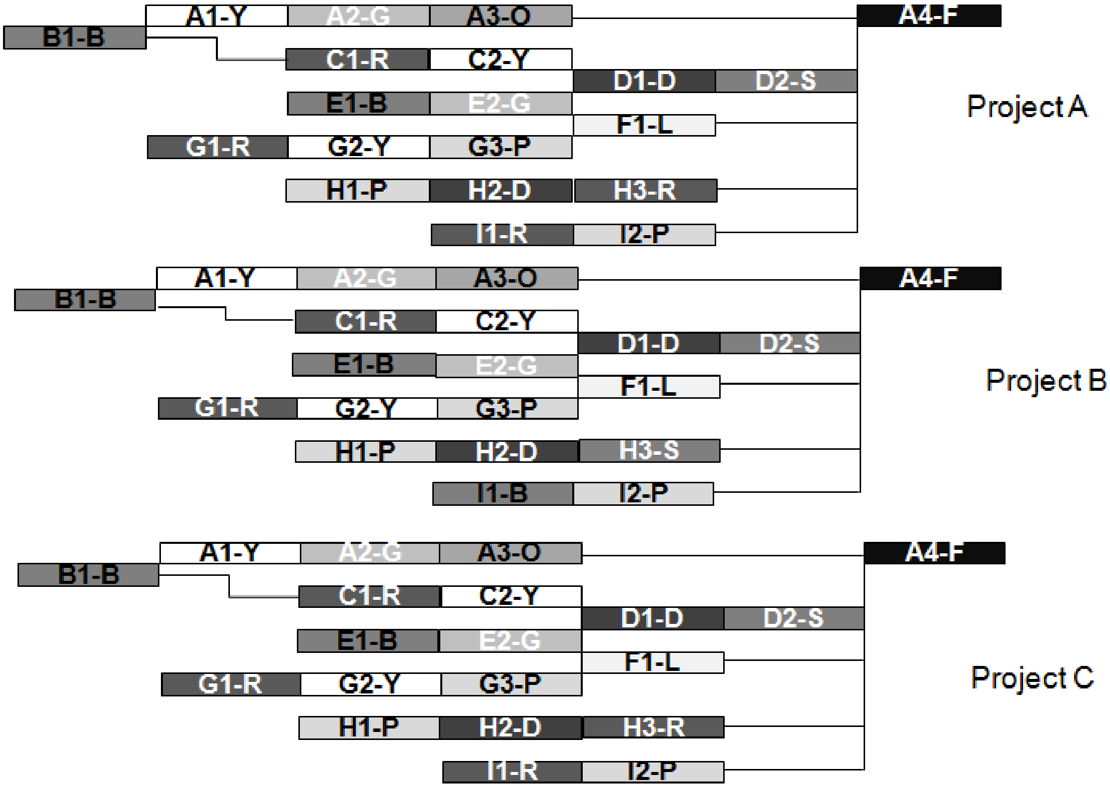
3. Using games and simulations to overcome first obstacle that block the introduction of CCPM to PM practitioners

Since it is difficult to overcome the obstacle that block the introduction of CCPM to PM practitioners through the collection and analysis of data obtained from directly in the field, therefore, in this chapter we invited experienced project managers, resources managers, and engineers to participate in an experiment with a series of multi-project management games. Game 1 was designed to reveal how teams manage the multi-project game with no problems outside of the project. Results were collected to identify the root cause of poor OTD, and served as a baseline to make comparisons with the other games. Games 2 and 3 were designed to gather data to support the notion that “mode of managing multi-projects” was the root cause and to validate that changing the mode of managing multi-projects (CCPM) could significantly improve OTD and PLT. Such measures include reasonable and reliable project plans (more efficient use of safety time embedded in each task), reductions in bad multi-tasking, prioritizing or working on the right priority (with a buffer management system), changing work behaviors (such as those related to student syndrome or Parkinson’s Law).

Because this experiment presents a valuable educational opportunity, we distributed an invitation letter to local manufacturing companies and invited them to organize one or more teams to participate in the experiment. The letter explained the purpose of the experiment, the time required, who should be team members and the value they could gain. The team members should be fulfilling the roles of project managers, task managers, and resource managers in their current organizational positions. The response was extremely good and thirty teams from twenty-five companies were soon selected. The number of years of working experience for each participant ranged from three to twenty-five years, with an average of seven years.

3.1. Design of multi-project management games

The multi-project management game used in this study was originally developed by Goldratt (1997b), and is modified slightly here to meet the needs of this research. The modified multi-project management game involves three similar projects (A, B, and C) as shown in Figure 3.1. Each project consists of several paths and 20 tasks, and involves 10 types of resources (engineers), most of whom must perform more than one task in each project. All the tasks have the same estimated task duration and are subject to the same variability. Though this setup is far from realistic, it still allows us to draw realistic conclusions while making it considerably easier to track the progress of each project. The estimated duration time for each task is 19 days with 90% confidence. Each project is laid out so that no resource is scheduled for two different tasks at the same time. These three projects were quite similar; with the same longest task and resources dependent path, which was B1-A1-G2-C2-D1-D2-A4. In terms of resource management, each project's planning is realistic, and the planned net time required to complete a project is 133 days. Since each type of resource has only one engineer, each engineer must work on all three projects. Although client requests the completion of all three projects within 247 days, however, the shorter time to the market the higher opportunity to capture large share of the market, so we ask each team has to determine due dates for their projects and will be evaluated according to the planned due dates. The project priority is project A > project B > project C.



A1-Y: Task A1 worked by resource type Y

Figure 3.1 A Multi-Project management game with three similar projects

Game 1: A multi-project management game

Game 1 was designed with no problems outside of the project. In this manner, the project team (game team) was able to obtain adequate resources (on time), with a good deal of safety time (enough project time to deal with uncertainty), receive swift decisions from customers and management, share information in a timely manner, with no supplier delivery delays, and no scope/specification changes, all the while receiving support from other project teams and senior management throughout the organization.

Because Game 1 was designed as a multi-project environment with no problems outside the project, achieving high OTD should not be difficult. If the results of the game were the opposite, the root cause of poor OTD could not be said to lie outside the problems of the project, but rather be attributed to the “mode of managing multi-project”. Accordingly, Games 2 and 3 were designed to gather data to support the notion that “mode of managing multi-projects” was the root cause and validate that changing the mode of managing multi-project (CCPM) could significantly improve OTD and PLT.

Game 1 required a team of seven players, three project managers, and four task managers. Each project manager led a project and each task manager led two to three pseudo engineers (meaning one task manager would play as two to three engineers) (Figure 3.2).

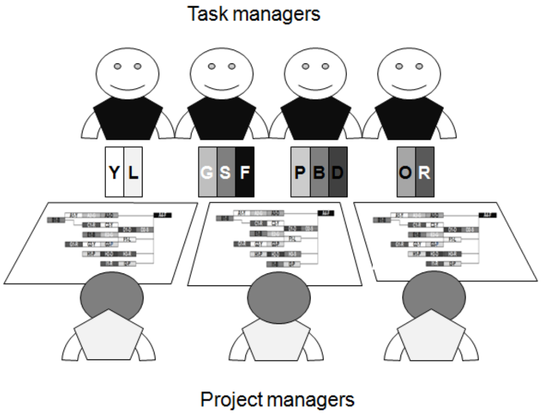
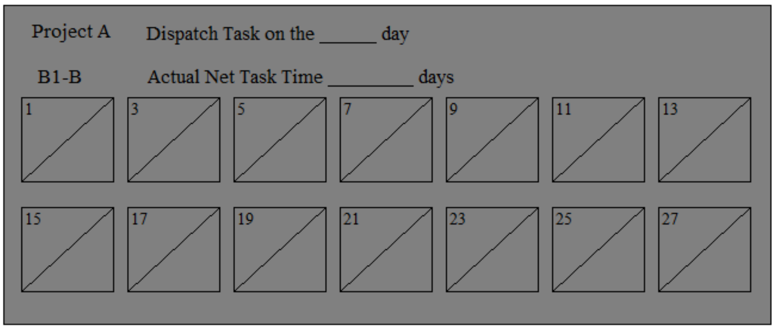


Figure 3.2 Layout of the game

Each task is designed as a task card shown in Figure 3.3. Each task card is associated with a task name and resource type needed for the task. For example, task “B1-B” represents task B1 worked by resource type B. Each task card has a maximum of twenty eight empty boxes depending on the actual net task time generated by the computer.

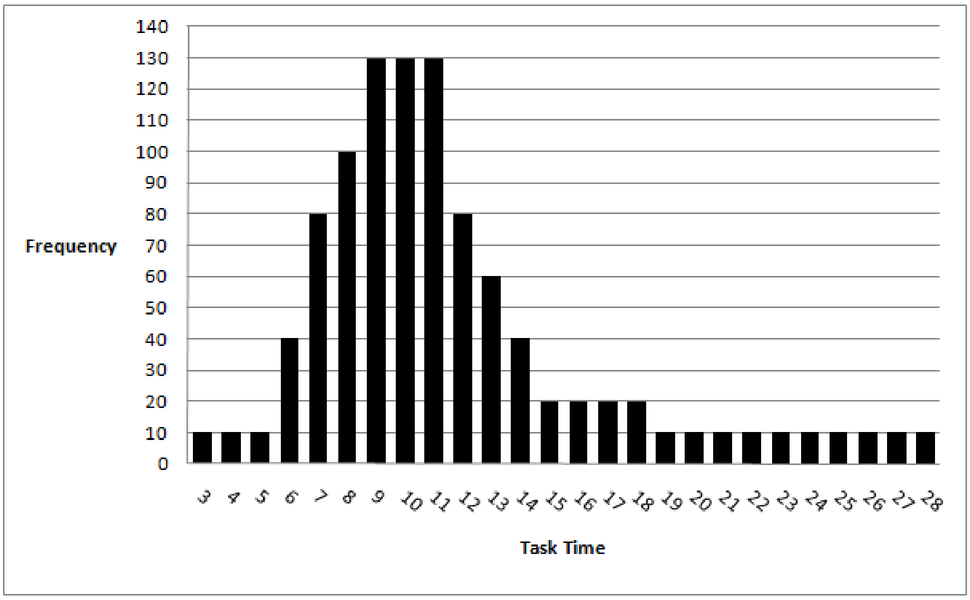

Project A Dispatch Task on the ______ day

B1-B Actual Net Task Time ________ days

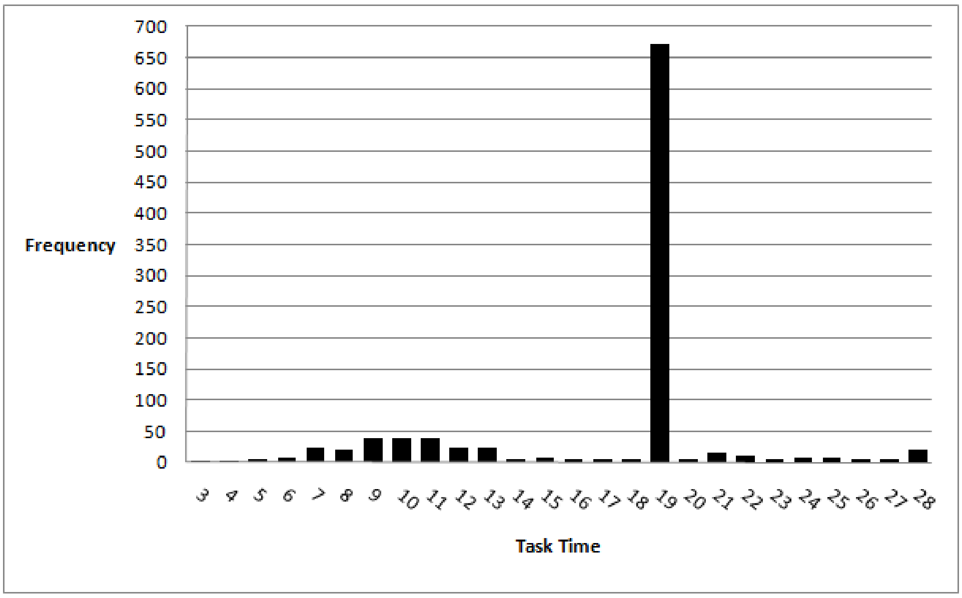
B-Blue: Task B1 worked by resource type B

Figure 3.3 Task Card

Before beginning the game, each team had to discuss how to manage the multi-project game and determine the delivery date for each project. Although the duration of each task was 19 days with 90% confidence, uncertainty still existed. The actual duration of tasks would range between 3 ~ 28 days as shown in Figure 3.4a.



(a)

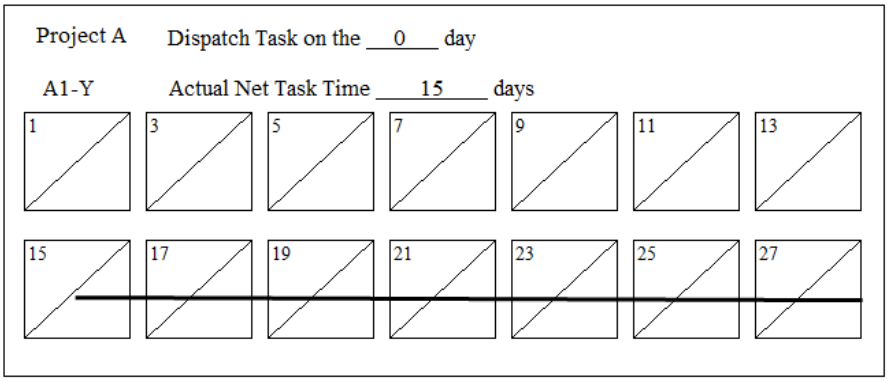


(b)

Figure 3.4 (a) Theoretical Estimated task time duration, (b) Actual task time duration

Although Parkinson's Law (Goldratt 1997b) (early finishes are not reported, i.e. work expands to fill the available capacity), student syndrome, and bad multitasking are quite natural working behaviors in reality, and because a game is a game, it was hard to ask participants to present these behaviors as they would have in reality. Therefore, we designed these behaviors into the game. For bad multi-tasking behavior, we defined a bad multi-tasking rule to be followed by all engineers. For each task card, engineers were able to work three days at most, before having to switch to another task card, unless only one task card remained in his hand (this would indicate whether they knew how to avoid bad multi-tasking). We considered both Parkinson's Law and the student syndrome in generating the actual net task time. Without Parkinson's Law and the student syndrome, 90% of the tasks' generated net task time should be within 19 days. With Parkinson's Law and the student syndrome, however, most actual net task time will change to equal or greater than 19 days. Figure 3.4b illustrates the probability task time duration distribution due to Parkinson's Law and the student syndrome. It is generated by PMSim (Goldratt 1997b) and assumes 25% of resources have no bad behaviors so that few of them (less 25%) will be within 19 days.

The games ran from day 0 until every team had completed their three projects. For each day, project managers had to determine if their projects had tasks that could be released to corresponding engineers (i.e., if prior tasks had already been completed). If new tasks were available, project managers would have to decide if they wanted to release the tasks to engineers. After deciding to release a task, they would generate an actual net task time with the computer, write down the release date, net task time, and cross out the extra box before handing it to the corresponding engineers. Figure 3.5 gives an example with net task time of 15 days. Each engineer would take one task card from his queue (if the queue contained any task cards), and writes the day (which the instructor calls out) in the first available empty box. When the empty boxes of a task card were full, the task would be complete, and the task card would be returned to the project manager. Each engineer was able to process just one task card per day. This process continues until all three projects had been completed. In these experiments, each team would attempt to use their intuition or experience to manage the experiment and achieve good OTD.


Project A Dispatch Task on the 0 day

A1-Y Actual Net Task Time 15 days

A1-Y: task A1 worked by resource type Y

Figure 3.5 Task card (front)

Game 2: A multi-project management game with no bad multi-tasking, while working on right priority

The differences between Game 2 and Game 1 were that in Game 2, bad multi-tasking was reduced by giving engineers only one task at a time. Rules concerning prioritizing (among projects) were defined and followed. The rules were: (1) For each day, that an engineer was available, one would always assign a "can be released task (its proceeded task(s) completed)" to the engineer, according to their project priority (project A>project B>project C). (2) For each day, if there were a "can be released task" of higher priority than the priority of the working task, the engineer (owner of the task) would be instructed to stop working on the task and would present the "can be released task" to the engineer. In this game, the teams would have done a good job reducing bad multi-tasking and would have avoided working on tasks in the wrong sequence of priority. Consequently, if the OTD of Game 2 were significantly better than in Game 1 and the data from Game 1 demonstrated that poor OTD was caused by bad multi-tasking and working in the wrong sequence of priorities, these two major causes could be shown to cause poor OTD in Game 1. The procedure was same as that for Game 1. This study also instructed each team member how to follow the rules. In both games, each of the team members was able to experience for themselves why the results were bad or good.

Game 3: A multi-project management game with no bad multi-tasking, while working on right priority with no bad human behaviors

There were two differences between Games 2 and 3: (1) In Game 3, student syndrome and Parkinson's Law were abolished. Because in Games 1 and 2, student syndrome and Parkinson's Law were assumed to exist, the generated actual task duration distribution was quite different from the theoretical distribution (Figure 3.4b), and the majority of tasks required 19 days. In this experiment, the absence of student syndrome and Parkinson's Law meant that the actual task duration distribution should have been equal to the theoretical distribution (Figure 3.4a). We expected favorable human behavior with less misuse (or waste) of the safety time. (2) The three projects were staggered according to the red resource (the most loaded resource), to determine the starting time of the first task of each path of the project and project deliver dates. Figure 3.6 shows the planned results. Having team members actually play the game was no longer necessary in this experiment, and PMsim computer simulation developed by Goldratt (1997b) was used. Each team ran the PMsim computer simulation in single run mode.

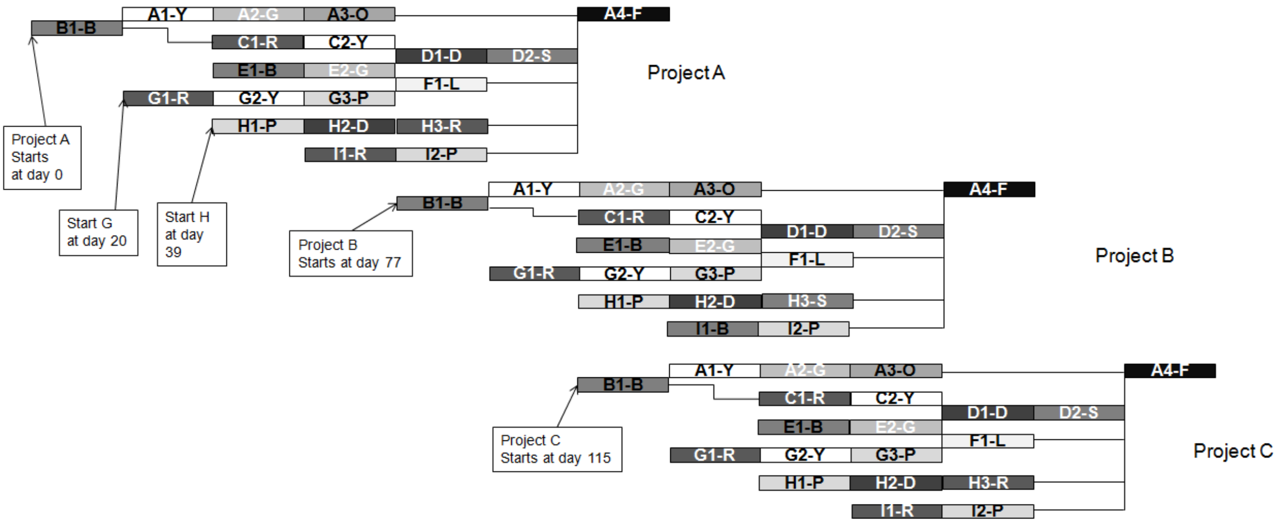


Figure 3.6 Multi-project plan

The guidelines for executing these three games were such that the first task of each path of the first project was scheduled according to time and the rest of the tasks were scheduled to correspond to the completion of the preceding task, rather than time (as early as possible), The experimental process was as follows: (0) Pre-game data collection (the root cause of poor OTD and long PLT) (1) Explaining the purpose of the experiment, (2) Explaining the game and conducting a 20 day (game day) trial run for process familiarization. (3) A thirty minute discussion among the game players of how to play the game to achieve better results. Each team had to determine completion dates for their projects. (4) Playing the game. (5) Analyzing and discussing the results of Game 1. (6) Explaining and playing Game 2. (7) Analyzing and discussing the results of Game 2. (8) Explaining and playing Game 3 with PMsim simulation. (9) Analyzing and discussing the results of Game 3. (10) Introduction of CCPM. (11) Post-game data collection. The experiment took approximately 6 hours to complete.

3.2. Analysis of the games and simulation experiment

Thirty teams participated in the three games experiment. Table 3.1 lists the experimental results of each team. Column one shows the planned delivery dates of the projects and column two is the actual delivery date of the projects in each of the three games. Dates with underlines are projects that were delivered on-time (if the actual deliver date was the same or earlier than the planned deliver date, the project was on-time).

Because the game was designed as a multi-project environment with no problems outside of the project, achieving high OTD should not have been difficult. Unfortunately, the results were the opposite. The OTD was only 31% (Table 3.1), only three teams (#15, #17 and

#20—high OTD teams) completed all three projects on-time, four teams (#1, #22, #23 and #25—medium OTD teams) completed two projects on-time, and the remaining 23 teams (poor OTD teams) completed either one project (10 teams) or zero project (13 teams) on-time. From the results, the conclusion can be made that the root cause could be said to be something other than problems outside of the project. However, we still do not know whether "the mode of project planning and execution" caused poor OTD of Game 1 we need further analysis.

Table 3.1 Results of three games

	Planned Completion Date			**Actual Completion Date**									**OTD***
				Game 1			**Game 2**			**Game 3**			
Teams	**Project A**	**Project B**	**Project C**	**Project A**	**Project B**	**Project C**	**Project A**	**Project B**	**Project C**	**Project A**	**Project B**	**Project C**	
1	133	209	247	133	238	247	144	197	226	113	169	202	M
2	214	214	238	219	219	295	133	216	256	117	176	188	P
3	166	190	214	150	216	290	136	207	239	106	170	196	P
4	185	214	238	192	226	254	115	173	240	117	178	191	P
5	128	166	219	183	190	249	140	204	245	113	163	192	P
6	154	202	247	143	223	252	152	183	257	124	160	194	P
7	152	209	247	188	238	257	142	207	226	107	159	213	P
8	143	219	242	171	214	280	135	216	268	99	170	209	P
9	124	181	214	204	214	276	138	226	278	117	181	192	P
10	195	214	238	211	235	242	165	213	257	102	181	190	P
11	162	219	247	159	238	266	136	204	235	116	167	211	P
12	166	214	238	166	226	280	128	197	230	108	184	196	P
13	214	238	247	214	247	257	170	192	218	91	168	191	P
14	190	214	238	214	247	257	133	202	235	114	159	211	P
15	143	219	247	143	214	247	131	211	280	101	162	207	H
16	152	214	247	143	223	261	131	216	245	122	177	185	P
17	157	209	247	157	200	247	124	209	245	92	166	202	H
18	190	214	238	209	226	254	166	190	240	91	166	200	P
19	185	219	233	188	223	257	175	219	240	120	168	216	P
20	166	200	247	162	171	247	148	207	245	99	155	192	H
21	143	219	228	219	190	261	140	207	242	99	168	186	P
22	143	214	247	143	169	257	141	198	247	129	149	189	M
23	171	219	247	143	209	249	138	204	240	118	163	183	M
24	171	200	214	188	226	268	134	220	240	93	160	208	P
25	138	219	247	138	209	252	138	155	240	96	165	203	M
26	166	190	214	192	214	299	116	202	240	127	178	187	P
27	190	214	247	190	238	254	152	204	252	111	177	194	P
28	147	214	247	173	221	245	138	181	249	95	170	187	P
29	162	185	209	147	247	271	135	209	245	103	169	178	P
30	209	228	247	214	238	257	126	221	252	107	176	234	P
Mean	165	209	237	176	219	261	140	203	245	108	168	197	
Due Date Performance				31.11%			66.67%			100%			

*__H__: High OTD teams; **M**: Medium OTD teams; **P**: Poor OTD teams.

Thirty minutes were given to them to discuss what reasons caused the poor OTD results in a multi-project management experimental game with no problems outside the project (addressed in the Chapter 1). We asked them to not just write the reasons they believe in, but what they experienced in the game. Table 3.2 lists the five top reasons.

Table 3.2 Five top reasons

Rank	Reasons
1	Working on the wrong priority (between projects)
2	Bad multi-tasking
3	Plan too aggressive
4	Lack of appropriate management mechanism
5	Bad luck

Analysis of projects plan reliability

To determine the reliability of the planned project completion day for the thirty teams, we simulated these three projects 1000 times with the theoretical task time distribution shown in Figure3.4a by PMsim (Goldratt 1997b). The simulation was designed according to the scheduling rule, in which the first task of each project path starts only at the planned start time, even if it can be started early (ALAP).Table 3.3 shows the results of this simulation. For example, for project A, if the planned completion day is at 143 days, this means the project can be completed within 143 days with 99% reliability. The reliability data of Table 3.3 shows that the projects of the high and medium OTD teams (Table 3.1), except for project B for teams #20, have high reliability. In other words, their projects were completed within the planned completion date, and their project plans were realistic (no over-promise the delivery day). However, for the poor OTD teams, the reliability of completing projects B and C by the planned completion date is low. Their project plans were unrealistic (over-promise the delivery day).

Table 3.3 Reliability of the planned completion day with simulation

Project A		Project B		Project C	
Planned completion date	**Simulate reliability**	**Planned completion date**	**Simulate reliability**	**Planned completion date**	**Simulate reliability**
100	0.1%	176	0.2%	219	0.2%
105	0.5%	181	0.8%	223	0.5%
109	13.1%	185	14.5%	228	13.7%
114	32.9%	190	24.8%	233	25.9%
119	51.3%	195	36.0%	238	43.0%
124	73.7%	200	53.0%	242	57.7%
128	81.3%	204	62.3%	247	74.7%
133	96.2%	209	76.7%		
138	97.6%	214	80.4%		
143	99.0%	219	84.8%		
147	99.1%	223	87.4%		
152	99.7%	228	90.9%		
157	99.8%	233	92.9%		
162	99.8%	238	95.0%		
166	99.9%	242	95.8%		
171	99.9%	247	97.1%		
176	99.9%	252	97.9%		
181	100.0%	257	98.7%		
		261	99.3%		
		266	100.0%		

Analysis the impact of bad multi-tasking and working on the wrong priority

Despite this, “mode of managing multi-project” could still not be identified as the root cause of the poor OTD results in Game 1. Table 3.1 shows that the OTD (approximately 67%) of Game 2 was significantly higher than Game 1. The differences between Game 2 and Game 1 were that in Game 2, bad multi-tasking was reduced by giving engineers only one task at a time and rules regarding correct prioritization (among projects) were defined and followed.

Table 3.4 shows the data related to project execution in Games 1 and 2. It consists of three columns; the average number of days of releasing the project early (compared with the planned release date of Game 3 shown in Figure 3.6), the increase in total task elapsed days (the time it takes from the start of a task until it is finished minus generated actual net task time) caused by bad multi-tasking, the total number of times working on the wrong priority (task was not executed following the project priority). Analysis of project execution data in Games 1 and 2 could provide information to indicate whether bad multi-tasking and working on the wrong priority were the major reasons for poor OTD in Game 1. Table 3.4 indicates that the data value (bad multi-tasking and working on the wrong priority) of the high and medium OTD teams in Game 1 (teams 1, 15, 17, 20, 22, 23 and 25) was significantly lower (or less serious) than the data value of the poor OTD teams. This means that OTD deteriorated when project execution data value increased. Comparing the data of Games 1 and 2 shows that the data value of Game 2 is significantly lower than the data of Game 1. This supports the assertion that reducing bad multi-tasking and working on the right priority would significant improve project OTD. This was consistent with the reasons for poor results concluded by thirty teams after Game 1.

Table 3.4 Data related to project execution in Game 1 and 2

Teams	Game 1			Game 2			OTD*
	Average days of releasing project too early	**Total task days increased by bad multi-tasking**	**Total number of times working on wrong priority**	**Average days of releasing project too early**	**Total task days increased by bad multi-tasking**	**Total number of times working on wrong priority**	
1	20	2	4	35	0	1	M
2	61	119	18	30	0	0	P
3	43	55	14	16	0	0	P
4	61	110	17	28	0	0	P
5	46	32	20	14	0	0	P
6	54	113	6	24	0	0	P
7	61	179	14	30	0	1	P
8	67	54	12	35	0	0	P
9	67	113	6	28	0	1	P
10	67	147	19	30	0	0	P
11	62	51	11	6	0	1	P
12	21	5	6	32	0	0	P
13	67	137	25	7	0	0	P
14	67	26	25	21	0	1	P
15	16	0	2	7	0	0	H
16	51	129	10	30	0	1	P
17	15	0	4	7	0	0	H
18	39	10	20	40	0	0	P
19	58	135	18	36	0	0	P
20	35	7	8	35	0	1	H
21	35	12	10	28	0	1	P
22	39	5	6	21	0	0	M
23	40	14	6	15	0	0	M
24	43	22	12	24	0	0	P
25	23	0	6	8	0	0	M
26	67	116	11	15	0	0	P
27	67	117	15	24	0	0	P
28	48	71	24	40	0	0	P
29	61	47	15	28	0	0	P
30	59	91	12	28	0	0	P
Mean	49	64	13	22	0	0.27	

***H**: High OTD teams; **M**: Medium OTD teams; **P**: Poor OTD teams.

Although the bad multi-tasking rule was deliberately designed into the game, while explaining the game we emphasized that limiting each resources to one task card on hand, multi-tasking could then be avoided. Only three teams (teams 15, 17 and 25) knew how to avoid bad multi-tasking. For example, on the first day of the game, except for these three teams, the number of blue tasks assigned for the blue engineer ranged between two and seven. This was because project managers feared projects would not finish on time, and they would release projects as soon as possible (see column one of Table 3.4). For the better OTD teams such as 1, 15, 17 and 25, their data value was much lower (releasing projects B and C much later) than the data value of poorer OTD teams. Releasing projects too early causes too many projects to be executed simultaneously, in which case many resources find themselves under pressure to work on more than one task; in such cases bad multi-tasking is unavoidable. Prolific bad multi-tasking drastically increases the lead time of tasks and of projects, leading to missed commitments. This reflects the fact that in the real world, multi-tasking is normal. It also reflects the common sense (one task at a time) is not common practice.

Data in column three of Table 3.4 of Game 1 indicates that working on wrong priorities is quite common and serious. Although the occurrence of working on the wrong priority in Game 2 was significantly reduced, most of the teams still had chances to work on wrong priorities. This indicates that without a system for prioritizing, following the lead of the project manager is not easy. This point was agreed upon by every team. The idea of giving an engineer only one task at a time is common sense, however, without a system of prioritization (among projects and within a project) this common sense notion is hard to put into practice. In such cases, bad multi-tasking behavior is difficult to reduce. A method of prioritization is therefore necessary. CCPM buffer management system is just such a method.

Comparing the data of column one in Games 1 and 2 indicates that “the average number of days of releasing the project too early” of Game 2 was significantly lower than the data of Game 1. This means projects B and C were released in Game 2 later than in Game 1. The target was not the number projects started; rather, it was the number of projects completed on time or earlier. Releasing projects late would reduce the chance of bad multi-tasking and increase the chance of working on the right priorities. The above analysis confirms Goldratt’s logical analysis of bad on-time delivery in a multi-project environment (Goldratt 1997b).

Analysis of the impact of student syndrome and Parkinson’s Law

Although the OTD of Game 2 significantly improved, 32% of projects were nonetheless delayed. Compared to the results of Game 2, Game 3, not only significantly improved OTD (from 68% to 100%), but also advanced the delivery dates of three projects. One must wonder what had contributed to this improvement. The major difference between Games 2 and 3 was that in Game 3, student syndrome and Parkinson's Law had been abolished. Both of these changes meant that the actual task duration distribution should have been equal to the theoretical distribution. This supports the notion that freedom from student syndrome and Parkinson's Law would decrease the misuse (or waste) of the safety time, leading to improved OTD as well as earlier delivery of the three projects.

Thus far, the three game experiments have validated that the root cause of poor OTD and long PLT in multi-project management is not due to those problems originating outside the projects; rather, the mode of managing multi-project. Reducing bad multi-tasking, prioritizing or working on the right priority (with a buffer management system) and changing work behaviors (such as student syndrome or Parkinson's Law**)** do effectively and significantly improve OTD and long PLT in multi-project management. Although reducing multi-tasking and following sensible priorities, avoiding student syndrome and Parkinson's Law are common sense notions; but again, common sense does not necessarily translate into common practice, in reality.

However, the results confirmed the views of the second critic from academia, who stated that reducing bad multi-tasking, prioritizing or working on the right priority, and changing bad human behaviors (such as student syndrome or Parkinson's Law**)** are not new. Therefore, does the mere emphasis on logistical change contribute to the success of project reduction and OTD improvement?

Introduction of CCPM and Post-game data collection

After the games, a three-hour of CCPM overview was given to the participants, We begin by stating that game is a game, it is still different from the reality and those problems originating outside the project still existed, can CCPM still handle those problems effectively? We then build upon this by introducing CCPM methodology (such as single project critical chain scheduling, multi-project staggering, buffer management), comparing and contrasting it to traditional PM methods such as CPM or PERT. Demonstrations and simulations are done to allow the participants to experience first-hand the differences between traditional PM methods and CCPM.

After the three-hour of CCPM overview, three polling questions were given to them: (1)

why is it difficult to achieve high OTD in multi-project management? (2) Can CCPM apply properly handle those problems originating outside the project? (3) Do you have confidence if CCPM being implemented will result better OTD and short PLT? Table 3.5 is the result, almost eighty percent gave a positive answer.

Table 3.5 Polling questions and answers before and after game

	Polling questions	**Answers**
Before	Why is it difficult to achieve high OTD in multi-project management	90% said excessive task time variability (or uncertainty).
	If they have adopted PDM and Six Sigma programs, was OTD improved significantly?	80% said OTD remained a major issue. Only 20% say OTD improved but take long-term effort.
After	Why is it difficult to achieve high OTD in multi-project management?	80% said the mode of managing multi-projects.
	Can CCPM apply properly handle those problems originating outside the project?	80% said CCPM can handle those problems originating outside the project.
	Do you have confidence if CCPM being implemented will result better OTD and short PLT?	80% said yes, they have confidence.

3.3 Conclusions

This chapter used games and simulation to overcome the first obstacle blocking the introduction of CCPM to project management practitioners, who have been less than confident that OTD and PLT can be significantly improved by simply changing the way to manage multi-projects. We designed a multi-project management experiment of three games and invited thirty teams of 210 people to participate in the experiment. In most cases, outside problems was not the true root cause of poor OTD or long PLT. Rather, the cause was the means by which multi-projects were managed. The results also supported the idea that by changing the mode of managing multi-projects (such as reducing bad multi-tasking, working on the right priorities, and changing bad human behaviors), project OTD and PLT can be improved significantly. Consequently, OTD and project lead time improvement programs should first focus on the mode of managing multi-projects, instead of continually seeking new management methods or remain can do little mentality.

In CCPM, logistical changes (plan aggressive task times with 50% buffers, stagger the release of projects, determine priorities with buffer management) and behavioral changes (no bad-multi-tasking, no student syndrome and no Parkinson’s Law) provide a new approach to managing multi-projects. Although behavioural changes are not unique to CCPM, good behavior is common sense but not common practice, in reality. CCPM insists that through logistical change, behavioural changes occur more easily, so that common sense can become a common practice (Yuji 2010).

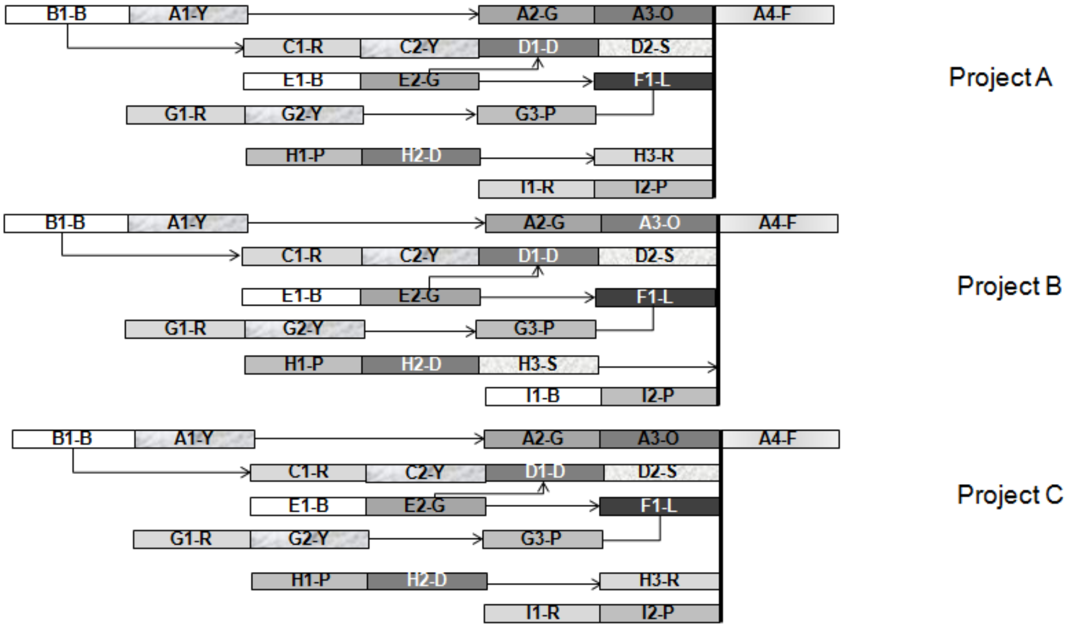
We expect these findings to raise the willingness of project management practitioners to re-examine whether the obstacle to the implementation of CCPM exist in their companies. They could play the game among their staff to experience first-hand the differences between their current mode and CCPM. In fact, these findings have given several participating manages the confidence to immediately switch from push mode to pull mode. These same companies showed significant improvements in their performance within a short period of time (Hwang 2011).

4. A comparative study of the CCPM excluding bad human behaviors to overcome the second obstacle

The results of last chapter confirmed the views of the second critic from academia, who stated that reducing bad multi-tasking, prioritizing or working on the right priority, and changing bad human behaviors (such as student syndrome or Parkinson’s Law**)** are not new. Therefore, does the mere emphasis on logistical change contribute to the success of project reduction and OTD improvement? To answer this question, a multi-project management simulation experiment was designed to conduct a comparative study of the critical chain and PERT planning method, without bad human behaviors. Because the planning (project time estimation) and execution methods affect the success of PLT reduction and OTD, we first compared the CCPM method with the PERT method to evaluate the planning results of the two methods regarding the same project networks and uncertainties. Second, we simulated both plans to evaluate OTD performance under different scheduling rules and evaluate a single project and multi-projects. Third, we then conclude with results.

4.1 Project Planning—CCPM vs PERT

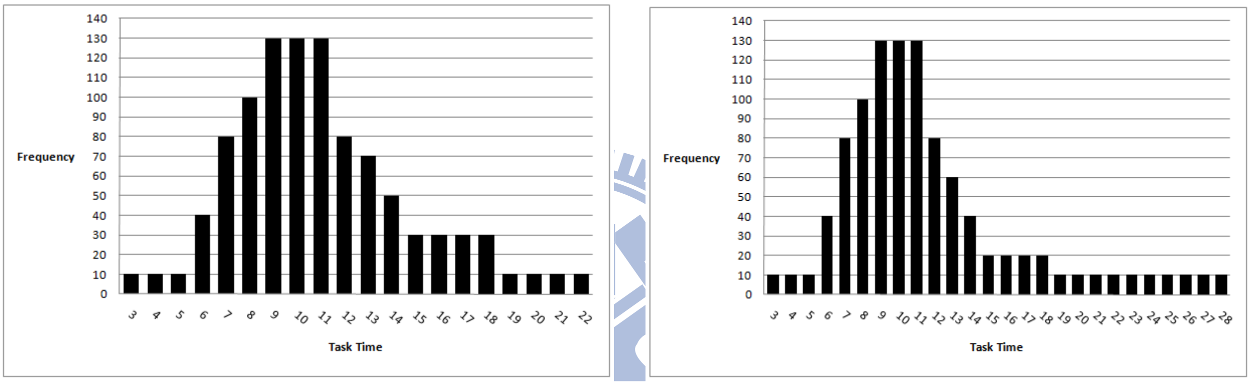
Figure 4.1 illustrates a multi-project environment involving three similar single project networks adopted from PMsim (Goldratt, 1997b). Each project network layout is as late as possible and does not level resources contention. Each project network consists of several paths, and 20 tasks involving 10 types of resources (engineers). Because each type of resource uses only one engineer, they all work on these three projects.



A1-Y: Task A1 worked by resource type Y

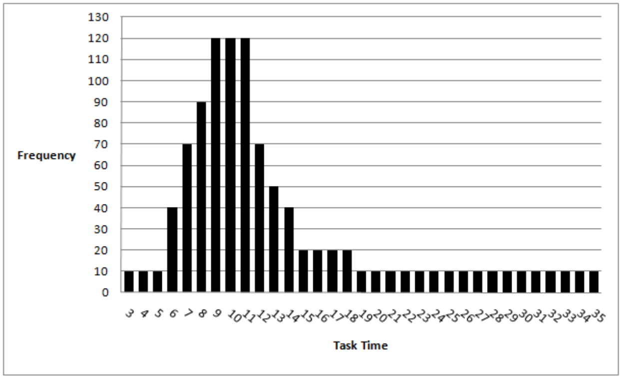
Figure 4.1Multi-Project environment involved three similar single project network

All tasks require the same amount of time and are subject to the same uncertainty, which makes it considerably easier to track the progress of the project. Although this is far from realistic, it did not prevent us from drawing realistic conclusions. This study analyzed three different task uncertainties low, medium, and high (shown in Figure 4.2). Beta distribution is assumed. The Beta distribution can be used to model events which are constrained to take place within a time interval defined by an optimistic time and a pessimistic time. Because both time value may vary in their relationship to the modal value (the most likely time), the unimodal probability distribution may be skewed to the right or to the left. Therefore, the Beta distribution –along with the triangular distribution—is used extensively in project management to describe the time to completion of a task.



(a) uncertainty low

(b)uncertainty medium



(c) uncertainty high

Figure 4.2 Three different task uncertainties, low, medium and high

Single project plan

Figure 4.3a illustrates the critical chain plan of project A (with uncertainty medium) conducted by the CCPM method. The CCPM method directly takes the 90th percentile of task distribution of Figure 4.2b as the estimated task time. The method cuts the estimated task time in half by placing the aggregated project buffer inserted at the end of the critical chain path and feeding buffer where the non-critical chain path feeds into the critical chain. The planned project duration is 100 days. The non-critical chain path is planned to start as late as possible, but with a feeding buffer. No resource was scheduled to perform two different tasks at the same time.

Figure 4.3b shows the project plan of project A using the traditional PERT method. The non-critical path is planned as early as possible, with full use of the float. Some paths such as C1-R, E1-B, and I1-R cannot start earlier because they are limited by resources and task dependence. Concerning the expected task time and project time estimation, PERT does not directly take the 90th percentile of task distribution of Figure 4.2 as the estimated task time. Instead, PERT uses the Equations below with three time estimates; optimistic, most likely, and pessimistic, to compute expected task time and project time:

Expected task time = (Optimistic time estimate + 4* Most likely time estimate + Pessimistic time estimate)/6 -----(1)

Standard deviation = (Pessimistic time estimate - Optimistic time estimate)/6 -----(2)

Since the longest path consists of seven tasks, B1-B, A1-Y, G2-Y, C2-Y, D1-D, D2-S, and A4-F and each task has the same expected task time, the expected project time of 90% confidence level is:

Expected project time = (Sum of the Expected task time of the longest path + Square root of the sum of Variances of the tasks on the longest path * 1.3) ----(3)

Where, 1.3 is the Z value of standard normal distribution with a 90% confidence level

For Project A, based on the expected project time equation, with the task time distribution of uncertainty medium (Figure 4.2b), the expected task time is equal to 11.8 days ((3+4*10+28)/6), and standard deviation is 4.17 days ((28-3)/6). The expected project duration is 97 days ((11.8*7 + (square root of 7*4.17*4.17)*1.3)). Table 4.1 shows the planned results where CCPM gives a longer expected project time than PERT; the higher the uncertainty, the bigger the difference is.

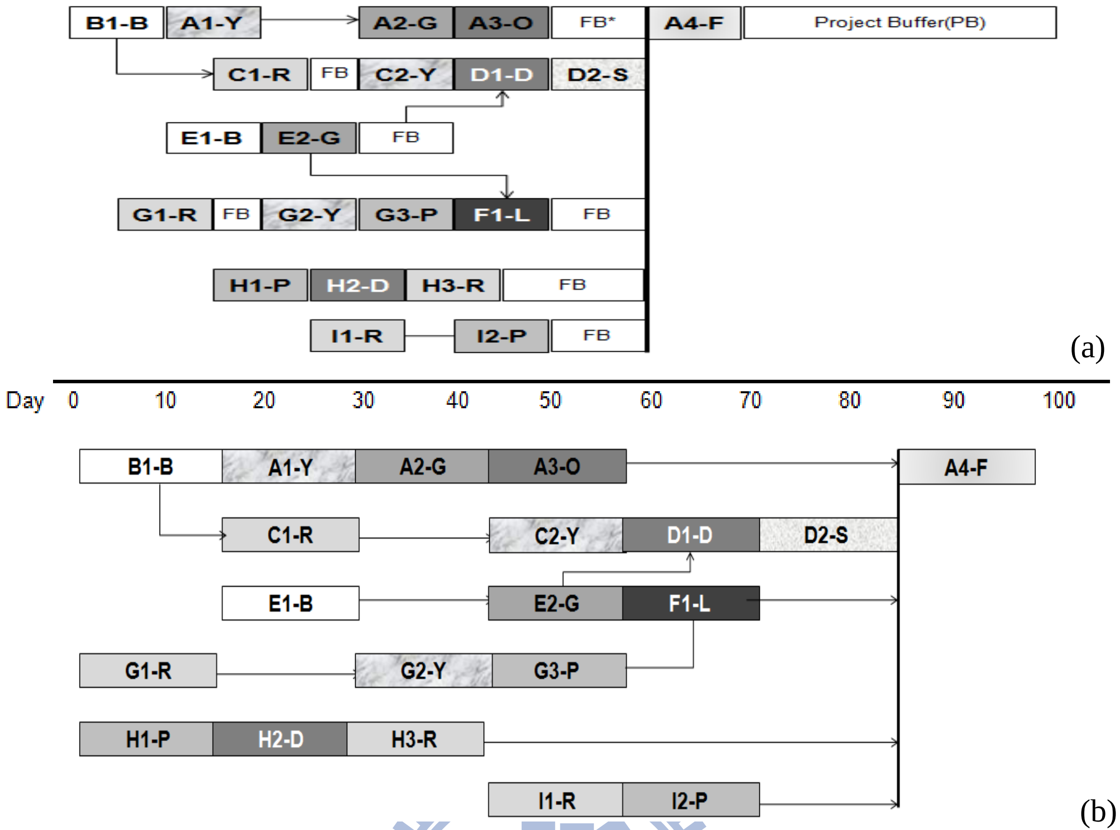


Figure 4.3 Single-Project CCPM/PERT with uncertainty medium

Table 4.1 Estimated duration of single project

	Uncertainty Low		**Uncertainty Medium**		**Uncertainty High**	
	PERT	**CCPM**	**PERT**	**CCPM**	**PERT**	**CCPM**
Estimated project time	87	90	97	100	114	137

Multi-project plan

Figure 4.4a illustrates the multi-project plan of the three single projects of Figure 4.1 using the CCPM multi-project plan method. The critical chain of each project was planned with the CCPM “Critical chain planning and buffering” method first. The three projects were then staggered according to the red resource (the most loaded resource), to determine the starting time and completion dates of each project. The CCPM multi-project plan method adds a synchronization buffer to prevent releasing projects too early (release projects as late as possible). Figure 4.4b shows the multi-project plan of the same three single projects using the PERT method. The critical path of each project is planned with the PERT method, which does not add the synchronization time buffer to the schedule of the highest loaded resource among projects.

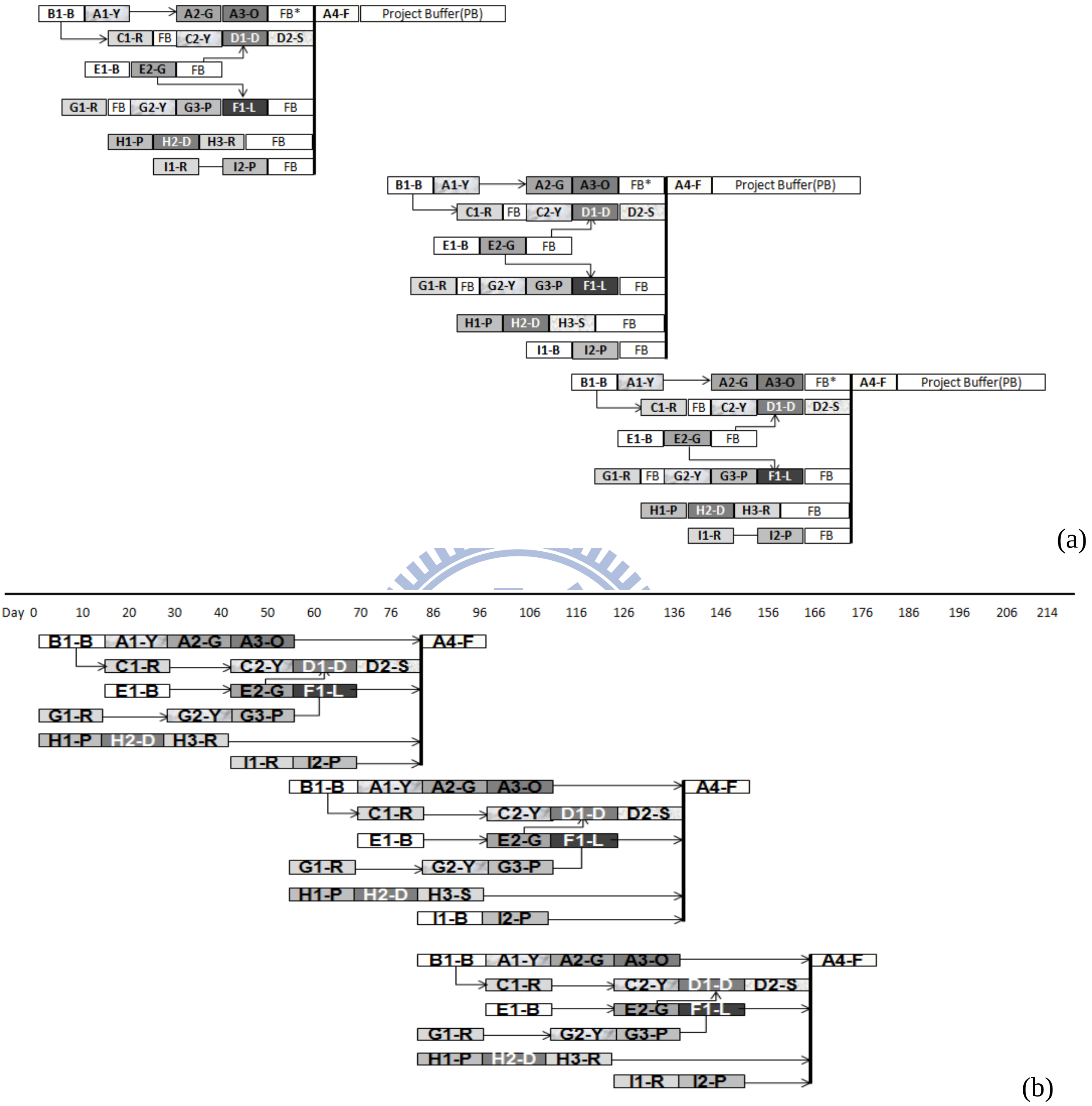


Figure 4.4 Multi-Project CCPM/PERT with uncertainty medium

Table 4.2 shows that the completion date of project B and C planned by CCPM are longer than those planned by the PERT method but shorter than those planned by CPM method. The main difference is due to the planned method of a single project with and without a synchronization buffer.

Table 4.2 Estimated duration of Multi-project

	Uncertainty Low						**Uncertainty Medium**						**Uncertainty High**					
	Project A		**Project B**		**Project C**		**Project A**		**Project B**		**Project C**		**Project A**		**Project B**		**Project C**	
	PERT	**CCPM**	**PERT**	**CCPM**	**PERT**	**CCPM**	**PERT**	**CCPM**	**PERT**	**CCPM**	**PERT**	**CCPM**	**PERT**	**CCPM**	**PERT**	**CCPM**	**PERT**	**CCPM**
Estimated project time	87	90	137	158	162	192	97	100	153	176	181	214	114	137	179	241	212	293

4.2 Project execution—CCPM vs. PERT

Project execution is designed to evaluate the mean project time and plan reliability of both CCPM and PERT methods. Our execution tool is a simulation model of PMsim developed by Goldratt (1997). Each simulation is replicated 1000 times. The computer randomly generates task duration time for each task based on the task time distribution shown in Figure 4.2. Data collected are mean project duration, its standard deviation, medium, and the 90th percentile. Bad human behaviors such as bad-multi-task, student syndrome, and Parkinson’s Law, do not exist.

Single project simulation

The CCPM plans for the non-critical chain path to start as late as possible, therefore the simulation was designed to start the first task of each path no earlier than its planned start time even if it can be started early (as late as possible, ALAP). The PERT method simulation was designed in two ways, One way starts the first task of each path immediately when it can be started (we call it PERT-SP-AEAP). Similar to CCPM, the other way starts the first task of each path no earlier than its planned start time even if it can be started early (we call it PERT-SP-ALAP).

Table 4.3 summarizes the results of our single project simulation. From the statistical hypothesis test of the population mean by the student t-test, no matter whether the uncertainty is low, medium, or high, the data show that the CCPM achieved significantly better mean project time than PERT-SP-ALAP did. However, from the statistical hypothesis test of the population mean using the student t-test, no matter whether the uncertainty is low, medium, or high, the data show that the CCPM is not significantly better than the PERT-SP-AEAP in achieving mean project time. Concerning planned reliability, CCPM achieved higher reliability than both PERT-SP-AEAP and PERT-SP-ALAP did.

Table 4.3 Simulation results of single project

N=1000	**Uncertainty Low**			**Uncertainty Medium**			**Uncertainty High**		
	PERT-AEAP	**CCPM**	**PERT-ALAP**	**PERT-AEAP**	**CCPM**	**PERT-ALAP**	**PERT-AEAP**	**CCPM**	**PERT-ALAP**
Medium	78	78	86	86	86	92	99	102	119
90th percentile (Estimated project time	92 (87)	91 (90)	94 (87)	103 (97)	102 (100)	107 (97)	123 (114)	124 (137)	137 (114)
Reliability	(80%)	(89%)	(71%)	(84%)	(89%)	(73%)	(80%)	(97%)	(49%)
Mean	80	80	86	87	87	94	102	103	120
Standard deviation	9.92	9.09	6.48	13.91	13.57	9.65	18.33	16.34	13.53
t value	0.00	17.00*		0.00	15.19*		-1.29	25.34*	

*Significantly reject the null hypothesis $H_0 : u_{PERT} - u_{CCPM} \leq 0$, at α=0.05 [$t_{0.05}(\infty) = 1.645$]

Multi-project execution

The CCPM plan method adds a synchronization buffer to prevent releasing projects too early (does not encourage starting a project early even if it can be started), therefore, the simulation was designed according to the scheduling rule, in which the first task of each project path starts only at the planned start time, even if it can be started early (ALAP). For the PERT method, the schedule rule within every project will be as early as possible (Table 4.3 shows the PERT-SP-AEAP achieved a better result). However, the scheduling rule among projects was designed in two ways. One is the same as the CCPM (we call it PERT-MP-ALAP). The other is that except for the tasks of B1-B, G1-R, and H1-P, where the first project will start at the planned start time, the rest of tasks of all projects will be started as soon as possible (we call it PERT-MP-AEAP).

Table 4.4 summarizes the results of our multi-project simulation. From the statistical hypothesis test of the population mean by the student t-test, no matter whether the uncertainty is low, medium, or high, the data show that the CCPM does not perform significantly better than PERT-MP-ALAP does. However, the statistical hypothesis test of the population mean by the student t-test shows that no matter whether uncertainty is low, medium, or high, the data show that the PERT-MP-AEAP achieves significantly better mean project duration than CCPM does, in terms of projects B and C. Concerning plan reliability, CCPM demonstrates higher reliability than PERT does. The higher the uncertainty, the better the planned result of CCPM is.

Table 4.4 Simulation results of Multi-project

N=1000	Uncertainty Low								
	Project A			Project B			Project C		
	PERT-AEAP	CCPM	PERT-ALAP	PERT-AEAP	CCPM	PERT-ALAP	PERT-AEAP	CCPM	PERT-ALAP
Medium	78	78	78	128	148	148	155	185	184
90th percentile (Estimated project time)	92 (87)	91 (90)	92 (87)	156 (137)	162 (158)	163 (137)	170 (162)	198 (192)	197 (162)
Reliability	(80%)	(89%)	(80%)	(68%)	(86%)	(20%)	(70%)	(80%)	(5%)
Mean	80	80	80	133	149	150	157	187	186
Standard deviation	9.92	9.09	9.92	17.15	13.17	14.59	13.41	13.82	13.92
t value	0.00		0.00	-23.40**		1.61	-49.27**		-1.61

N=1000	Uncertainty Medium								
	Project A			Project B			Project C		
	PERT-AEAP	CCPM	PERT-ALAP	PERT-AEAP	CCPM	PERT-ALAP	PERT-AEAP	CCPM	PERT-ALAP
Medium	86	86	86	142	162	162	170	204	202
90th percentile (Estimated project time)	103 (97)	102 (100)	103 (97)	169 (153)	182 (176)	182 (153)	190 (181)	222 (214)	222 (181)
Reliability	(84%)	(89%)	(84%)	(75%)	(87%)	(30%)	(80%)	(80%)	(27%)
Mean	87	87	87	143	163	164	171	206	204
Standard deviation	13.91	13.57	13.91	19.78	19.08	19.56	15.24	13.83	13.21
t value	0.00		0.00	-23.01**		1.16	-53.78**		-3.30**

N=1000	Uncertainty High								
	Project A			Project B			Project C		
	PERT-AEAP	CCPM	PERT-ALAP	PERT-AEAP	CCPM	PERT-ALAP	PERT-AEAP	CCPM	PERT-ALAP
Medium	99	102	99	166	202	202	204	261	259
90th percentile (Estimated project time)	123 (114)	124 (137)	123 (114)	203 (179)	227 (241)	230 (179)	231 (212)	285 (293)	284 (212)
Reliability	(80%)	(97%)	(80%)	(70%)	(96%)	(13%)	(67%)	(95%)	(1%)
Mean	102	103	102	172	205	205	207	264	260
Standard deviation	18.33	16.34	18.33	24.98	24.78	21.03	19.30	17.41	19.46
t value	-1.29		-1.29	-29.66**		0.00	-69.35**		-4.84**

**Significantly reject the null hypothesis $H_0 : u_{PERT} - u_{CCPM} \geq 0$, atα=0.05 $[-t_{0.05}(\infty) = -1.645]$

Results finding

The project plan and execution results show that if excluding bad human behaviors, we can draw several findings as follows:

1. No matter for a single project plan or a multi-project plan, with 90% confidence level, the CCPM plan is much more conservative (longer project time and longer project completion date) than the PERT plan. The higher uncertainty, the more conservative it is.

2. For single project execution, no matter whether the uncertainty is low, medium, or high, the results show that the CCPM is not significantly better than the PERT-SP-AEAP in achieving mean project duration. For multi-project execution, no matter whether the uncertainty is low, medium, or high, the results show that the PERT-MP-AEAP significantly achieves better mean project duration than CCPM does in terms of projects B and C.

3. Although from the mean project time result, CCPM is no better than PERT, however, from plan reliability, no matter whether uncertainty is low, medium, or high, the simulation result shows that CCPM achieves higher reliability. This means that using the Equation (3) to estimate the project duration time and not adding a synchronization time buffer to the schedule of the highest loaded resource among projects such as CCPM did, PERT allows for too short a project duration time and too tight a completion date. The higher uncertainty, the worse the result will be.

4. Realistically, few project practitioners will use Equation (3) to estimate task time and project time. They typically take the 90th percentile of task distribution of Figure 4.2 as the task time (CPM (Critical Path Method) typically takes the 90th percentile of task distribution as the task time). Table 4.5 illustrates the plan results using this procedure and re-planning the project with the PERT plan method. Comparing the CCPM and PERT plan with the project time estimate of equation (3) yields a much longer project time and longer project completion date. Comparing the planned results with the simulation results of Tables 4.3 and 4.4, no matter whether uncertainty is low, medium, or high, projects can be completed with nearly 100% reliability. This means that directly taking the 90th percentile of task distribution of Figure 4.2 as the task time, the PERT plan will result in too conservative a plan, making it less competitive.

Table 4.5 Plan results

	Uncertainty Low									**Uncertainty Medium**									**Uncertainty High**								
	Project A			**Project B**			**Project C**			**Project A**			**Project B**			**Project C**			**Project A**			**Project B**			**Project C**		
	CPM	**PERT**	**CCPM**	**CPM**	**PERT**	**CCPM**	**CPM**	**PERT**	**CCPM**	**CPM**	**PERT**	**CCPM**	**CPM**	**PERT**	**CCPM**	**CPM**	**PERT**	**CCPM**	**CPM**	**PERT**	**CCPM**	**CPM**	**PERT**	**CCPM**	**CPM**	**PERT**	**CCPM**
Estimated Project time	119	87	90	187	137	158	221	162	192	133	97	100	209	153	176	247	181	214	182	114	137	286	179	241	338	212	293
Reliability	100%	80%	89%	100%	68%	86%	100%	70%	80%	100%	84%	89%	100%	75%	87%	100%	80%	80%	100%	80%	97%	100%	70%	96%	100%	67%	95%

5. From the simulation, if excluding bad human behaviors, the expected task time estimation method, the schedule rule (within project and between projects), and task time distribution are the three major factors that affect the result of both methods.

From the above findings, if excluding bad human behaviors, and if the schedule rule for PERT is AEAP within project and between projects, in terms of mean project time, the CCPM method is no better than the PERT method because of logistical change. However, from our study, we identify two merits of the CCPM method over the PERT method.

1. Concerning the project plan, CCPM logistical change can plan a higher reasonable and reliable project plan than the PERT method because PERT either underestimates the project completion date (using Equation (3)) or overestimates (by directly taking the 90th percentile of task distribution of Figure 4.2 as the estimated task time). Simulation results support that no matter whether uncertainty is low, medium, or high, CCPM demonstrates a higher reasonable and reliable project plan due to logistical change.

2. The scheduling rule that CCPM uses is as late as possible (within project and between projects). Scheduling a non-critical path and projects as late as possible is advantageous in delaying costs and avoiding bad multi-tasking. However, with the PERT plan, scheduling a non-critical path and projects as late as possible increases the probability of delaying the project because of no safety buffer to handle uncertainty (simulation results support this point), so scheduling as early as possible is always preferable. The CCPM with project and feeding buffers can tell when not to start and will not hurt the project being delay. This is also the contribution of CCPM logistical change.

4.3. Conclusion

This chapter investigated whether the emphasis on logistical change contributed to the success of project reduction and OTD improvement when no bad human behaviors were involved by comparing the critical chain and PERT planning methods. The current study implemented a three-project environment for simulation using the CCPM and PERT method. The results show that in terms of mean project time, CCPM is not significantly better than PERT-AEAP. However, in terms of plan reliability, CCPM achieves better than PERT-AEAP. This is due to CCPM logistical change that generates a more reasonable and reliable project plan than the PERT method. The CCPM with project and feeding buffers can tell when not to start and will not hurt project being delay.

Realistically, assuming that bad human behaviors do not exist is impractical. The Goldratt study (1977) proved that if adding bad human behaviors into the simulation, that even if taking the 90th percentile of task distribution of Figure 4.2 as the estimated task time (see Table 4.5), the OTD is not 100% reliable, but very poor. However, whether bad human behaviors exist or not, the important point is how to reduce them. CCPM logistical change is one of the best ways to reduce bad human behaviors.

5. Conclusion

This study used games and simulations to overcome two obstacles blocking the introduction of CCPM to project management society. The first is from project management practitioners, who have been less than confident that OTD and PLT can be significantly improved by simply changing the way to manage multi-projects. The second is from academia: some scholars have claimed that the ideas of CCPM are not new and are of no real contribution to PMBOK. In this study, we first designed a multi-project management experiment of three games and invited thirty teams of 210 people to participate in the experiment. A comparative study of CCPM and PERT/CPM planning methods, without bad human behaviors, was then performed to overcome the second obstacle. In most cases, outside problems was not the true root cause of poor OTD or long PLT. Rather, the cause was the means by which multi-projects were managed. The results also supported the idea that by changing the mode of managing multi-projects (such as reducing bad multi-tasking, working on the right priorities, and changing bad human behaviors), project OTD and PLT can be improved significantly. Consequently, OTD and project lead time improvement programs should first focus on the mode of managing multi-projects, instead of continually seeking new management methods or remain can do little mentality. In terms of mean project time, CCPM is not significantly better than PERT or CPM. However, in terms of plan reliability, CCPM achieves higher than PERT or CPM. This is due to the CCPM logistical change that generates a more reasonable and reliable project plan than does the PERT method. The CCPM with project and feeding buffers can indicate when not to start and will not delay a project. However, whether bad human behaviors exist or not, how to reduce them is the critical point.

In CCPM, logistical changes (plan aggressive task times with 50% buffers, stagger the release of projects, determine priorities with buffer management) and behavioral changes (no bad-multi-tasking, no student syndrome and no Parkinson’s Law) provide a new approach to managing multi-projects. Although behavioural changes are not unique to CCPM, good behavior is common sense but not common practice, in reality. CCPM insists that through logistical change, behavioural changes occur more easily, so that common sense can become a common practice (Yuji 2010).

Although this study validated the effectiveness of CCPM in multi-project management, there was no intention to identify CCPM as the only method to improve OTD and project lead times. Instead, we intended to make it clear that regardless of the method used to improve OTD and project lead times, four fundamental concepts are essential (Goldratt 2008, Jacob and Mendenhall 2008 and Kapoor 2009): (1) Improving flow (or equivalently lead time) is a primary objective of project management. (2) This primary objective should be translated into a practical mechanism to guide the project management in determining when to release (prevent misallocation). Rules to prevent misallocation are: limit the number of projects being executed, use time buffers instead of space, and provide task-level priorities (3). Local efficiency must be abolished, as should metrics such as measuring project level instead of task level. Resources should no longer be judged according to time estimates (lead to behavioral change). Adhering to the flow concept mandates the abolishment of local efficiencies. (4) A focused process to balance flow (not balance capacity) must be in place. Analyze buffer consumption to identify opportunities for improvement.

Implementing the CCPM can lead to success or failure, depending on how it is implemented. There is no doubt that the paradigm shift associated with migrating away from a traditional method to CCPM will noticeably impact all stakeholders (participants in the project management such as project managers, task managements, resources managers, and senior executives). Whether this impact is positive or negative depends on how well it is understood by stakeholders, partnership robustness, the mechanics for information exchange, and most importantly, its financial implications for everyone involved (Cox and Schleier, Jr 2010). Goldratt has developed a PM Strategy and Tactics (S&T) trees (Goldratt, 2009) to provide step by step guidance for effecting change. Although the S&T tree logic developed by Goldratt is quite robust, TOC practitioners and academics have neither researched it extensively nor validated its effectiveness empirically. This would make a good research topic for future researches.

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Appendix A

Customer	Before	After
ABB AG, Power Technologies Division Electrical Power Transmission, Engineer-to-Order	Throughput was 300 bays per year.	Throughput increased to 430 bays per year.
ABB Córdoba Power Transformers, Engineer-to-Order	Engineering cycle time was 8 months. On-time delivery was 85%.	Engineering cycle time reduced to 3 months. On-time delivery improved to 95%. 16% increase in manufacturing throughput (revenues).
ABB, Halle Transformer Repair and Overhaul	42 projects completed in 2007. On-time delivery was 68%.	54 projects completed in 2008. On-time delivery improved to 83%.
Action Park Multiforma Grupo Theme Park Design, Install and Commissioning	121 projects completed in 2004.	142 projects completed in 2005. 153 projects completed in 2006.
Alcatel-Lucent Telecomm Switches Design, Development & Upgrades	300-400 active projects with 30+ deliveries a month. Lead times were long. On-time delivery was poor.	Throughput increased by 45% per person. Lead times shortened by 10-25%. On-time delivery improved to 90+%.
Alna Software Customized Software Development	Growth was stagnating, becoming insufficient to secure market position.	Throughput increased by 14% in the first 6 months. Cycle time reduced by 25% and project completions increased 17% with over 90% on-time delivery.
Amdocs Customer Experience Systems Customized SW Development for Telecommunications	Market pressure to reduce cost and cycle time. 8 projects in crisis requiring CEO level attention in 2007.	14% increase in revenue/man-month. 20% reduction in cycle time. 0 projects in crisis in 2008.
Airgo Networks (Qualcomm) Next Generation Wireless Technology Product Development	Cycle time from first silicon to production for 1st generation was 19 months.	Cycle time from first silicon to production for 2nd generation was 8 months.
Alcan Alesa Technologies Material Handling Solutions, Engineer-to-Order	Completed an average of 6.9 projects per year.	Completed 10 projects in first 8 months of 2009. 31% increase in throughput-dollars.
Army Fleet Support Helicopter Maintenance, Repair and Overhaul (For Flight Schools)	Maintenance workload increased by 37% and turnaround times were long, leading to helicopter shortages.	32% reduction in CH-47 turnaround time. 52% reduction in UH-60 turnaround time. 8 aircraft returned to customer ($90M in cost avoidance). 18,000 sq ft of hangar space freed up ($2M in cost savings).
BHP Billiton Iron Ore Asset Development Projects	25,800 man-hours of engineering design work had to be completed in 8 months. Historical delays of 2 weeks and man-hour overruns of 20%.	Project finished 3 weeks early. Productivity increased by 25% with only 19,500 man-hours needed.

Customer	Before	After
Boeing Space & Intelligence Systems Satellite Design and Assembly	Reflectors were the constraint in Antenna and Satellite delivery. Electronic units were late, delaying Satellite subsystems. Classified Government program was behind schedule and losing money. Operation was losing $200M a quarter.	Doubled Reflectors throughput and reduced cycle time by 28%, alleviating delivery constraint. Increased productivity in Antenna Assembly and Test by 64% and subsequently another 26%. Reduced cycle time for Electronic units, allowing subsystems to finish 30% faster. Stabilized schedule and returned money to Government 4 quarters in a row. Operation turned profitable.
C.N. Cofrentes (Iberdrola) Nuclear Power Engineering	Due-date performance was 60%.	Due-date performance increased to 95%. Throughput increased by 30%.
Celsa Group IT Projects	15 SAP functionality projects were completed per month.	SAP functionality project completions increased by 30% to 20 projects a month.
Central Nuclear Almaraz Trillo Nuclear Power Engineering	19 design evaluation and modification projects were being completed per month.	Throughput increased by 25% to 24-30 projects per month.
Chrysler Automotive Product Development	Cycle time for prototype builds was 10 weeks.	Cycle time for prototype builds reduced to 8 weeks.
Danisco (Genencor International) Biotechnology Plant Engineering	20% projects on time.	87% projects on time. 15% immediate increase in throughput.
Delta Air Lines, Inc. Aircraft Engine Repair and Overhaul	476 engines produced per year. 4-8 weeks piece-part cycle time. 60 days landing gear turnaround time.	586 engines produced per year (23% increase). 30% reduction in engine turnaround time. 15 days piece-part cycle time (70% reduction). 25% increase in throughput. 30 days landing gear turnaround time (50% reduction). $60M monetized in assets from reduced turnaround time. **On going improvement:** 10 days piece-part turnaround time (30% further reduction).
Dr. Reddy’s Laboratories Pharmaceutical New Product Development	6 projects completed in first 12 weeks. 20% projects on time in 12 weeks. 85 global generics and PSAI filings in 2009. 85 product launches in 2009. 915 days cycle time for full development in 2008.	11 projects completed (83% increase). 80% projects on time (60% increase). 110 filings in 2010 (30% increase). 149 launches in 2010 (75% increase). 563 days cycle time for full development in 2010 (40% faster).
e2v Semiconductors Semiconductor Design and Manufacturing	Actual cycle time of projects was 38 months; 25% of projects were on time.	Actual cycle time reduced to 23 months; almost all projects are within the committed cycle time of 24 months.
eircom Telecommunications Network Design & Installation	On-time delivery was less than 75%. Average cycle time was 70 days.	Increased on-time delivery to 98+%. Average cycle time dropped to 30 days.

Customer	Before	After
Emcocables Manufacturing Plant Construction	11 months industry standard project duration.	7 months to project completion. (55% additional revenue 4 months earlier).
Emesa TGV Station Construction	6 months left to deliver, and project was 5 months late.	Completed 11 months of work in 6 months. Project on time (€5M penalty avoided).
Erickson Air-Crane Helicopter Manufacturing and Maintenance	Only 33% projects completed on time.	On-time delivery increased to 83%.
French Air Force, SIAé Clermont Ferrand Transall Production Line Aircraft Upgrade and Repair	5 aircraft on station. Cycle time of 165 days	3 aircraft on station, 2 aircraft returned to Air Force, a replacement value of €300 M. 15% cycle time reduction, 15% increase in output with 13% fewer resources; 22% reduction in support shops' cycle time.
Hamilton Beach Brands, Inc. New Product Development Home Appliances	34 new products per year. 74% projects on time.	Increased throughput to 52 new products in 1st year, and to 70+ in 2nd year, with no increase in head count. 88% projects on time.
Heineken, Spain CPG New Product Development	150 projects per year. 90% on-time delivery.	20% faster time-to-market. 98% on-time delivery. 10% of projects finished ahead of schedule.
HP Digital Camera Group Digital Camera Product Development	6 cameras launched in 2004. 1 camera launched in spring window. 1 out of 6 cameras launched on time.	15 cameras launched in 2005. 7 cameras launched in spring window. All 15 cameras launched on time.
Ismeca Semiconductor Engineer-to-Order	84 days overall cycle time. 24 days production cycle time. 15 machines in 8 months was highest ever throughput.	64 days overall cycle time (25% reduction). 10 days production cycle time (60% reduction). 22 machines in 5 months (47% higher throughput). 22% improvement in EBIT.
LeTourneau Technologies, Inc. Oil & Gas Platform Design & Manufacturing	Design Engineering took 15 months. Production Engineering took 9 months. Fabrication and Assembly took 8 months.	Design Engineering takes 9 months. Production Engineering takes 5 months. Fabrication and Assembly takes 5 months with 22% improvement in labor productivity.
LSI Logic ASIC Design Technology Development	74% projects on time for small projects. Major tool releases were always late.	85% of small projects on time. Major tools released on time for three years in a row.
Marketing Architects Advertising Product Development	Completed 7 projects in 2006.	Completed 7 projects in first 8 months of 2007.
Medtronic High Tech Medical Product Development	1 software release every 6-9 months. Predictability was poor on device programs.	1 software release every 2 months. Schedule slips on device programs cut by 50%.
Medtronic, Europe High Tech Medical Product Development	Device projects took 18 months on average and were unpredictable.	Development cycle time reduced to 9 months. On-time delivery increased to 90%.

Customer	Before	After
Oregon Freeze Dry Food Preparation & Packaging	72 sales projects completed per year.	171 sales projects completed per year. 52% increase in throughput-dollars.
Owens-Illinois Process Manufacturing Plant Engineering	6 month cycle time for furnace design. 45 projects/year engineering throughput.	2.5 months cycle time (58% faster). 60 projects/year throughput (33% increase).
Railcare Wolverton, UK Train Maintenance, Repair, and Overhaul	16 month delay in delivery of last order. 1 order executed at a time.	100% on-time delivery on all orders. 3 orders executed in the same timeframe.
Rapid Solutions Group Marketing/Publishing Support	Projects were always late. Lead times were not acceptable.	On-time delivery improved by 30%. Lead times reduced by 25%.
Siemens Generator Engineering Electric Generator Engineering	110 projects completed in 11 months. Low overall throughput.	128 projects completed in 11 months. 30% increase in overall throughput. 44% increase in non-project throughput.
Škoda Power Engineered-to-Order Steam Generators	20 casings per year. 60% on-time delivery.	27 casings per year (30% increase). 90% on-time delivery. 20-30% faster cycle time.
Skye Group Garment Design	Product ranges were late to market.	100% due-date performance. 30% reduction in lead times and sampling costs.
Spirit Aerosystems Aircraft Engineering	12 months was best case engineering cycle time.	On track to finish pylon project in 7 months.
TATA Steel Plant Maintenance and Upgrade	300-500 days for boiler conversion. Routine maintenance took too long. 11 days planned for shutdown. $2M revenue generated per day	120 - 160 days completion time (68% faster). 10 - 33% reduction in 2007 cycle time. 5 - 33% additional reduction in 2008 cycle time. 8.8 day shutdown achieved. $4M revenue gained. *Set net operating hours industry record (6690 hours per year).*
TECNOBIT Defense Products Design and Manufacturing	Long project cycle times with frequent delays. Difficult to synchronize Design and Manufacturing.	Project cycle times reduced by 20%.
ThyssenKrupp (Johann A. Krause, Inc.) Automotive Assembly Systems, Engineer-to-Order	70% of projects were late. High overtime and outsourcing.	Lateness reduced by 50%. 63% gains in productivity. 15% more projects completed.
US Air Force Operational Test & Evaluation Center Warfighter Systems Testing	Long cycle times. Low utilization of resources. Poor visibility of project slips.	30% reduction in cycle time measured over 900 projects. 30% improvement in resource utilization. 88% on-time delivery performance.
US Air Force, Ogden Air Logistics Center **572nd AMXG** **C130 Production Line** Aircraft Maintenance, Repair, and Overhaul	33 aircraft throughput in FY09. 36 aircraft on station.	44 aircraft throughput in FY10 (33% increase). 24 aircraft on station, 12 aircraft returned to Air Force.

Customer	Before	After
US Air Force, Oklahoma City Air Logistics Center **B-1 Production Line** Aircraft Repair and Overhaul	Turnaround time 162 days. 7 aircraft in repair cycle.	Turnaround time reduced to 115 days. 4 aircraft in repair cycle (3 returned to customer). Production output increased from 185 hours/day to 273. 1 ½ dock spaces freed up (additional revenue potential $35M).
US Air Force, Oklahoma City Air Logistics Center **B52 Production Line** Aircraft Upgrade and Repair	Produced 11 aircraft a year. Cycle time of 225 days.	Produced 17 aircraft a year. Cycle time of 195 days.
US Air Force, Oklahoma City Air Logistics Center **E3 Production Line** Aircraft Upgrade and Repair	4 aircraft on base. Cycle time of 183 days.	2.6 aircraft on base on average. Cycle time of 155 days. 11% capacity released for additional workload.
US Air Force, Oklahoma City Air Logistics Center **KC135 Production Line** Aircraft Maintenance, Repair and Overhaul	Average turnaround time was 327 days.	Average turnaround time reduced to 146 days. 44% increase in throughput from Q4 2008 to Q4 2009.
US Air Force, Tinker Air Force Base, 76th PMXG Aircraft Engine Repair and Overhaul	**Engine piece-part repair:** 137 days backshop cycle time. 260 parts/month backshop throughput. **Engines and Modules:** 45 modules/month throughput. 18 days cycle time.	**Engine piece-part repair:** 42 days backshop cycle time (69% reduction). 434 parts/month throughput (67% increase). **Engines and Modules:** 50 modules/month throughput (10% increase). 8 days cycle time (55% reduction).
US Air Force, Warner Robins Air Logistics Center **C17 Production Line** Aircraft Upgrade and Repair	Throughput of 178 hours per aircraft per day. Turnaround time 46-180 days. Mechanic output was 3.6 hours per day.	25% increase in throughput. Turnaround time reduced to 37-121 days. Mechanic output increased to 4.75 hours per day. 40% reduction in overtime.
US Air Force, Warner Robins Air Logistics Center **C5 Production Line** Aircraft Repair and Overhaul	Turnaround time 240 days. 13 aircraft in repair cycle.	Turnaround time 160 days. 7 aircraft in repair cycle. 75% fewer defects.
US Army, Corpus Christi Army Depot Helicopter Maintenance, Repair and Overhaul	Throughput of 5.4 aircraft per month. Throughput for Black Hawk was much lower than required. Turnaround times were unacceptable. Work scope per aircraft was increasing.	Throughput increased to 6.3 aircraft per month. Black Hawk throughput increased by 40% in just 6 months. 50% reduction in Apache turnaround time. 15% reduction in CH47 turnaround time. 15% reduction in Pave Hawk turnaround time despite increased scope.

Customer	Before	After
US Department of Defense Procurement Organization Processing of Purchase Requests	Long delays in processing requests. Long cycle times.	Delays reduced by 40%. 76% reduction in cycle time. 29% increase in throughput.
US Marine Corps Logistics Base, Barstow Army Vehicles Maintenance and Repair	Repair cycle time for MK48 was 168 days. Repair cycle time for LAV25 was 180 days. Repair cycle time for MK14 was 152 days. Repair cycle time for LAVAT was 182 days.	Repair cycle time for MK48 reduced to 82 days. Repair cycle time for LAV25 reduced to 124 days. Repair cycle time for MK14 reduced to 59 days. Repair cycle time for LAVAT reduced to 122 days.
US Naval Aviation Depot, Cherry Point Aircraft Repair and Overha	Average turnaround time for H-46 was 225 days. Average turnaround time for H-53 was 310 days. Throughput was 23 aircraft per year	Reduced H-46 turnaround time to 167 days, while work scope was increasing. Reduced H-53 turnaround time to 180 days. Delivered 23 aircraft in the first 6 months. Throughput increased to 46 aircraft per year.
US Naval Shipyard, Pearl Harbor Submarine Maintenance and Repair	Job completion rate was 94%. On-time delivery was less than 60%. Cost per job was $5,043.	Job completion rate increased to 98%. Increased on-time delivery to 95+%. Reduced cost per job to $3,355, a 33% reduction. Overtime dropped by 49%, a $9M saving in the first year.
US Navy, Fleet Readiness Center Southeast, P-3 Aircraft Maintenance and Upgrades	Produced 6 aircraft in 2008.	Produced 9 aircraft in the first 9 months of 2009.
Valley Cabinet Works Custom Furniture Design and Manufacturing	Struggled to complete 200 projects per year. Revenues were flat, business was just breaking even.	Completed 334 projects in the first 9 months. Revenues increased by 88% and profits by 300%.
Von Ardenne Equipment for Manufacturing Solar Panels, Engineer-to-Order	Revenues of €130 M. Profits of €13 M. Cycle time was 17 weeks. On-time delivery was 80%.	Revenues of €170 M. Profits of €22 M. Cycle time reduced to 14 weeks. On-time delivery improved to 90%.
Votorantim Process Plant Turnaround (Nickel Smelting)	Projects were late and over budget.	Project 1 delivered on time. Project 2 delivered 1 day earlier (with 10% extra scope). Actual cost was 96% of planned budget.