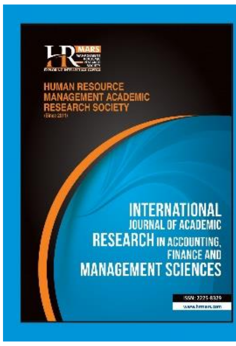


INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN ACCOUNTING, FINANCE AND MANAGEMENT SCIENCES

HR MARS MANAGEMENT ACADEMIC RESEARCH SOCIETY
EXPLORING INTELLECTUAL CAPITAL
www.hrmars.com
ISSN: 2225-8329

A Study of Using Simulation to Overcome Obstacles that Block the Implementation of Critical Chain Project Management to Project Management Environment

Chia-Ling Huang, Rong-Kwei Li, Chih-Hung Tsai, Yi-Chan Chung, Yao-Wen Hsu

To Link this Article: http://dx.doi.org/10.6007/IJARAFMS/v4-i1/505 DOI:10.6007/IJARAFMS /v4-i1/505

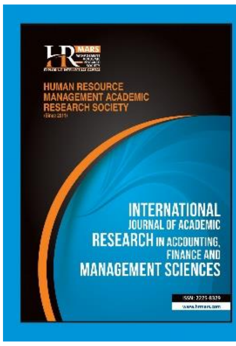
Received: *09* January *2014*, ***Revised:*** *10* February 2014, ***Accepted:*** *23* February 2014

In-Text Citation: (Huang et al., 2014)

To Cite this Article: Huang, C-L., Li, R-K., Tsai, C-H., Chung, Y-C., Hsu, Y-W. (2014). A Study of Using Simulation to Overcome Obstacles that Block the Implementation of Critical Chain Project Management to Project Management Environment. *International Journal of Academic Research in Accounting Finance and Management Sciences. 4(1),* 30 - 48.

Vol. 4, No. 1, 2014, Pg. 30 - 48

http://hrmars.com/index.php/pages/detail/IJARAFMS JOURNAL HOMEPAGE



INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN ACCOUNTING, FINANCE AND MANAGEMENT SCIENCES

HR MARS MANAGEMENT ACADEMIC RESEARCH SOCIETY
EXPLORING INTELLECTUAL CAPITAL
www.hrmars.com
ISSN: 2225-8329

A Study of Using Simulation to Overcome Obstacles that Block the Implementation of Critical Chain Project Management to Project Management Environment

Chia-Ling Huang[1], Rong-Kwei Li[2], Chih-Hung Tsai[3], Yi-Chan Chung[4], Yao-Wen Hsu[5]

[1]Department of Logistics and Shipping Management, Kainan University, Taoyuan, Taiwan, [2]Department of Industrial Engineering and Management, National Chiao-Tung University, Hsinchu, Taiwan, [3]Department of Information Management, Yuanpei University, Hsinchu, Taiwan, [4]Department and Graduate Institute of Business Administration, Yuanpei University, Hsinchu, Taiwan, [5]Department of Industrial Engineering and Management, Ta-Hwa University of Science and Technology, Hsinchu, Taiwan
Email: imtch@mail.ypu.edu.tw (Corresponding author)

Abstract

Since 1997, the Critical Chain Project Management (CCPM) method 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 implementation 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 Project Management Body of Knowledge (PMBOK). In this study, we first used multi-project management games to overcome the first obstacle. A comparative study of CCPM and Program Evaluation and Review Technique/Critical Path Method (PERT/CPM) planning methods, excluding bad human behaviors, was then conducted to overcome the second obstacle. The simulation 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.

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

Introduction

Since Dr. Goldratt first published the Critical Chain book in 1997 (Goldratt, 1997a), proposing the Critical Chain Project Management method, 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 (Newbold, 1998/2008; Leach, 2004; Yuji, 2010) and conducted research to enhance and spread CCPM knowledge (Steyn, 2000/2002; Rand, 2000; Herroelen and Leus, 2001; Herroelen *et al.*, 2002; Elmaghraby *et al.*, 2003; Cohen *et al.*, 2004; Ashtiani *et al.*, 2007; Jacob and Mendenhall, 2008; Long and Ohsato, 2007/2008; Liu and Xie, 2008; Rezaie *et al.*, 2009; Cui *et al.*, 2010), developed software systems (Realization Technologies Inc., 2011; ProChain Solutions Inc., 2011) to support CCPM implementation, and created implementation strategy and tactics to guide practitioners in how to implement CCPM (Goldratt, 2009).

Critical Chain Project Management method (CCPM) 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 Technologies Inc., 2011; Goldratt Marketing Group, 2011), the implementation 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 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 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 sever 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.

We realized unless it is experienced by managers themselves, we could not convince them that 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. 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 this study.

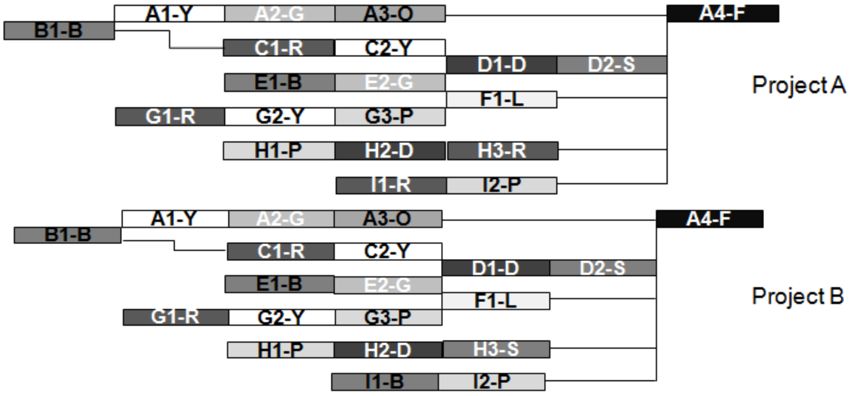
Concerning the critics from academia, two major criticisms include the shortcomings and lack of novel ideas in CCPM. About the first critic, one of the most significant shortcomings in CCPM claimed by them is the lack of mathematical analysis, specifically, in buffer sizing determination (Ashtiani *et al.*, 2007; Liu and Xie, 2008; Long and Ohsato, 2008; Rezaie *et al.*, 2009), critical chain identification (Long and Ohsato, 2007; Cui *et al.*, 2010; Zhao *et al.*, 2010), and priority control (Cohen *et al.*, 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 (1997b) 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.

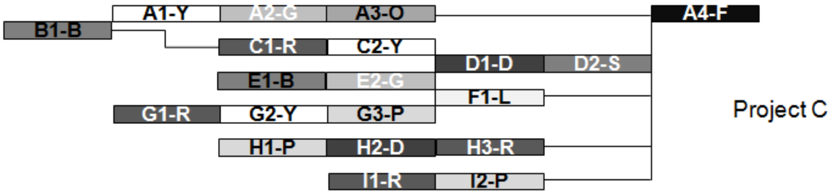
Concerning the second critic, Duncan (1999); Trietsch (2005) have argued that although CCPM presents some good ideas as new insights, these ideas are not new. They have claimed that the project management literature has thoroughly documented changing bad human behaviors, such as reducing bad multi-tasking. 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 (2000, 2002) 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); Goldratt and Goldratt (2003) with their simulation results pointed out that mere emphasis on logistical change CCPM outperforms with no logistical change in terms of OTD and short PLT. 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, 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. 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 Program Evaluation and Review Technique (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 this study.

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 1. Each project consists of seven 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 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 2). Each task is designed as a task card shown in Figure 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. 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 4a.

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.

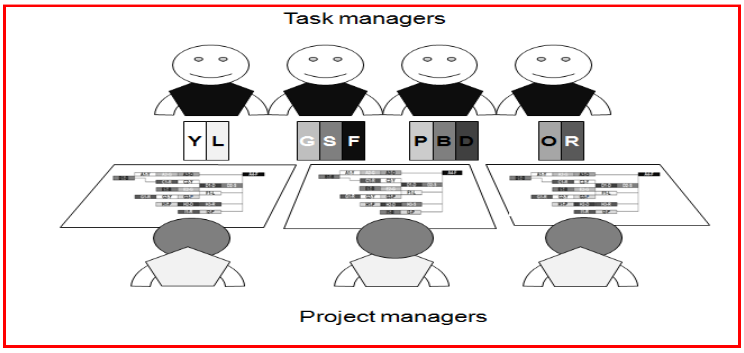
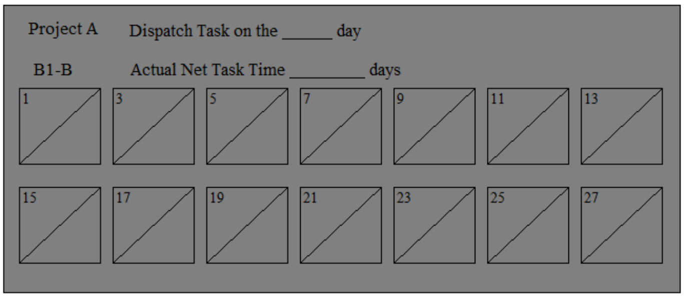


Figure 2. Layout of the game



Project A Dispatch Task on the ______ day

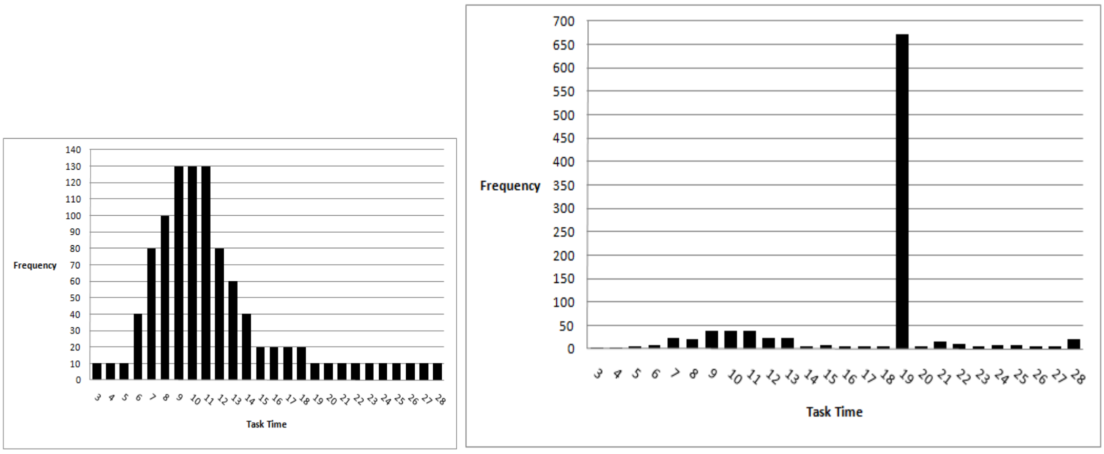
B1-B Actual Net Task Time ________ days

1 3 5 7 9 11 13

15 17 19 21 23 25 27

B: Blue: Task B1 worked by resource type B

Figure 3. Task Card

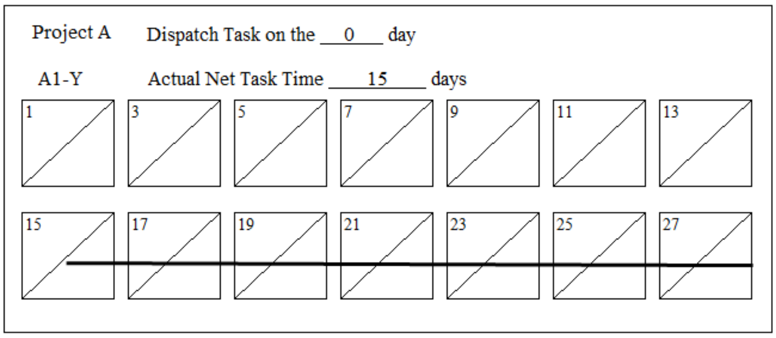


(a) **(b)**

Figure 4. (a) Theoretical Estimated task time duration; (b) Actual task time duration.

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 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 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.



A1-Y: task A1 worked by resource type Y

Figure 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 DDP 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 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 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 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.

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), 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. We asked team members to be project managers, task managers, and resource managers in real life. 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.

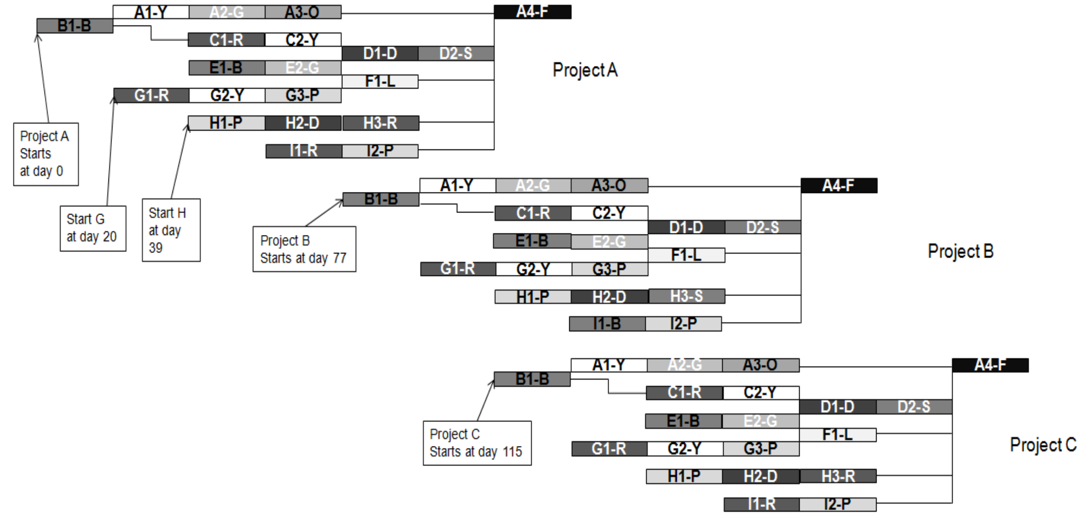


Figure 6. Multi-project plan

The experimental process was as follows: (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. The experiment took approximately 6 hours to complete.

Design of multi-project Management Simulation Experiment

The simulation experiment was designed to determine if mere emphasis on logistical change (excluding bad human behaviors) contributes to the success of project reductions and OTD improvement. The PERT method was selected to contrast the CCPM. Three different task uncertainties, low, medium, and high (shown in Figure 7), were elevated. Figure 8a illustrates the multi-project plan of the three single projects of Figure 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 CCPM method directly takes the 90th percentile of task distribution 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, with uncertainty medium (Figure 7b), is 100 days. Figure 8b shows the multi-project plan of the same three single projects using the PERT method.

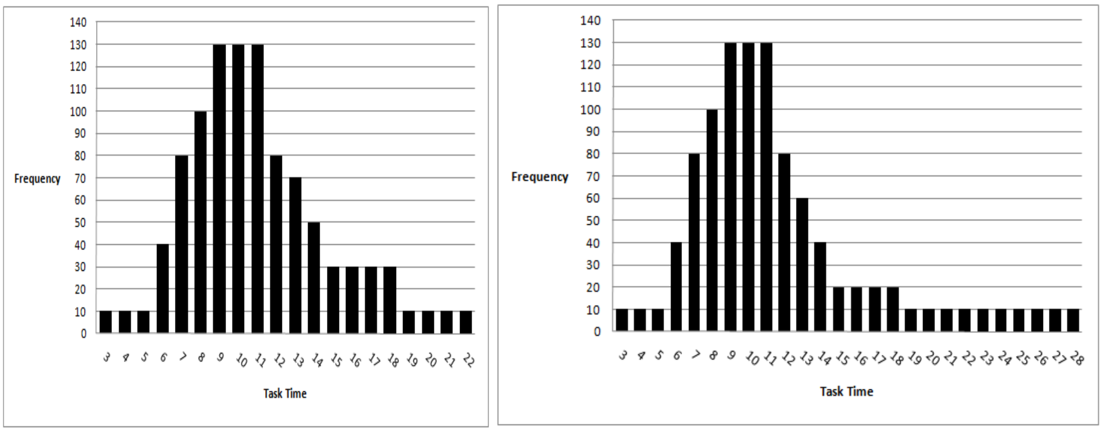
The PERT method involves the equations below with three time estimates, optimistic, most likely, and pessimistic, to compute expected task time and project time.

Expected task time = (Optimistic time estimate + 4 × Most likely time estimate + Pessimistic time estimate)/6.

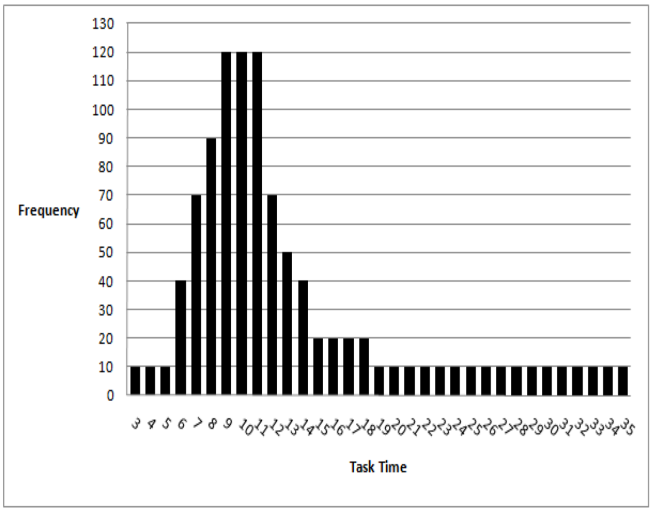
Standard deviation = (Pessimistic time estimate - Optimistic time estimate)/6.

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).

For Project A, based on the expected project time equation, with the task time distribution of uncertainty medium (Figure 7b), 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 + 1.3 * (square root of 7*4.17*4.17))). 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. Table 1 show that the completion date of project B and C planned by CCPM are longer than those planned by the PERT method. The main difference is due to the planned method of a single project and with or without a synchronization buffer between projects.

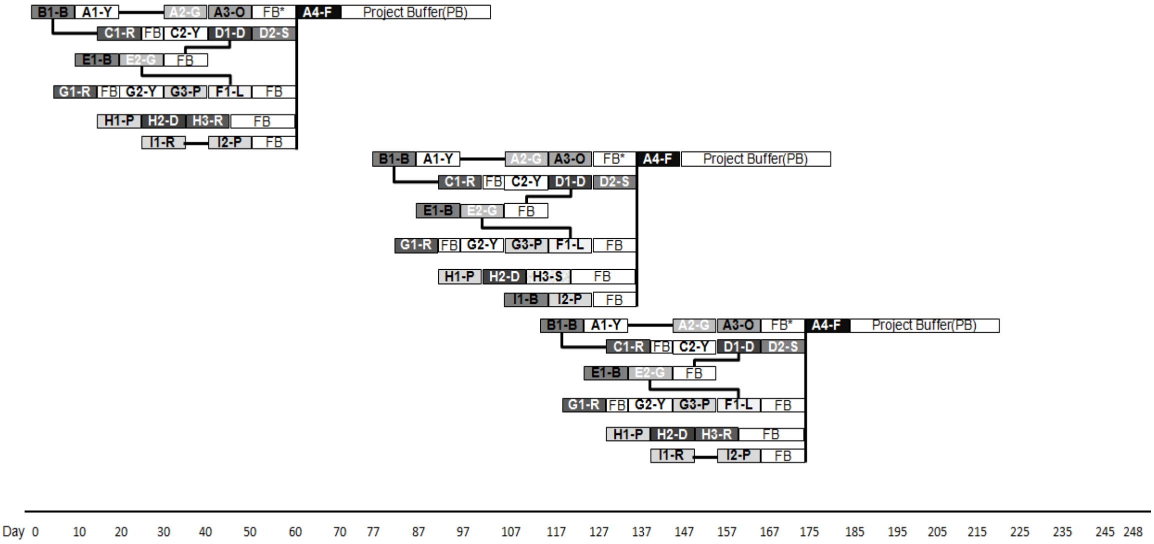


(a) **(b)**

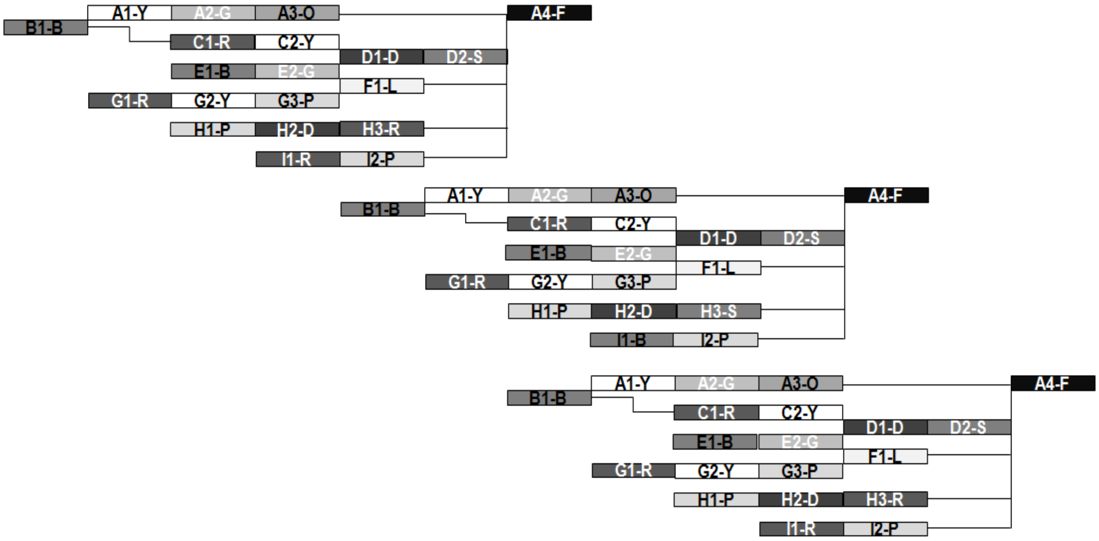


(c)

Figure 7. Theoretical estimated task time distribution with three different task uncertainties: (a) Uncertainty low; (b) Uncertainty medium; (c) Uncertainty high



(a)



(b)

FB: Feeding Buffer

Figure 8. (a) Multi-Project CCPM Plan; (b) Multi-Project PERT Plan

Table 1. Estimated project time of projects A, B and C with PERT and CCPM methods

	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

Because 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. However, the scheduling rule among projects was designed in two ways. One is the same as the CCPM (PERT-ALAP). The other is that except for the tasks of B1-B, G1-R, and H1-P of the first project will start at the planned start time, the rest of tasks of all projects will be started as soon as possible (PERT-AEAP). The experimental tool is a simulation model of PMsim developed by Goldratt (1997b). Each simulation is replicated 1,000 times. The computer randomly generates task duration time for each task based on the task time distribution shown in Figure 7. 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.

Analysis of the Games and Simulation Experiment

Thirty teams participated in the three games experiment. Table 2 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).

Analysis the Impact of bad Multi-tasking and Working on the Wrong Priority

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 2), therefore the root cause could be said to be something other than problems outside of the project. 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 2 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 2

Results of three games

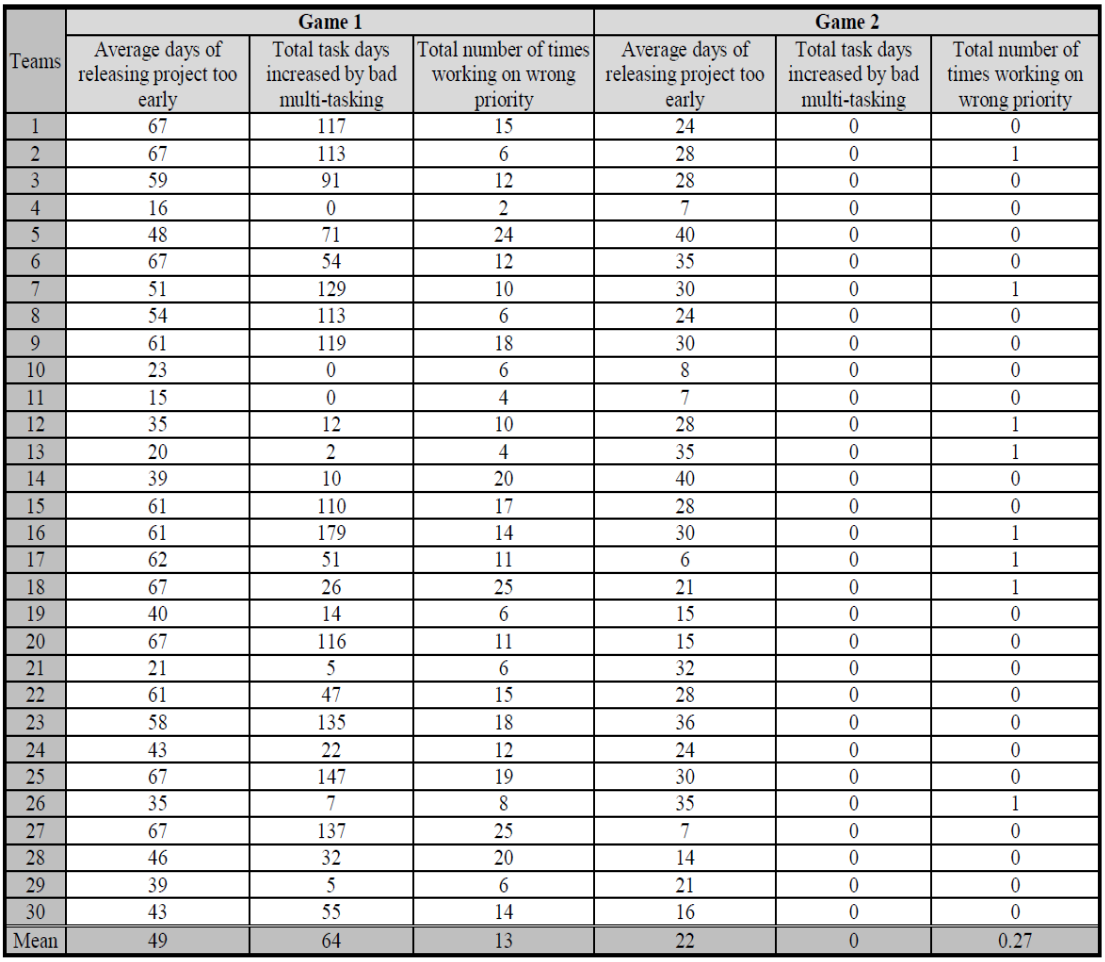
	Planned Completion Date			Actual Completion Date								
				Game 1			Game 2			Game 3		
Teams	Project A	Project B	Project C	Project A	Project B	Project C	Project A	Project B	Project C	Project A	Project B	Project C
1	190	214	247	190	238	254	152	204	252	111	177	194
2	124	181	214	204	214	276	138	226	278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

Table 3 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 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 indicates that the data value (bad multi-tasking and working on the wrong priority) of the high OTD teams in Game 1 (teams 4, 10, 11, 13, 19, 26 and 29) 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.

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 4, 10 and 11) 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). For the better OTD teams such as 4, 10, 11 and 13, their data value was much lower (releasing projects A and B much later) than the data value of poorer OTD teams.

Table 3

Data related to project execution in Game 1 and 2



Teams	Game 1			Game 2		
	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	67	117	15	24	0	0
2	67	113	6	28	0	1
3	59	91	12	28	0	0
4	16	0	2	7	0	0
5	48	71	24	40	0	0
6	67	54	12	35	0	0
7	51	129	10	30	0	1
8	54	113	6	24	0	0
9	61	119	18	30	0	0
10	23	0	6	8	0	0
11	15	0	4	7	0	0
12	35	12	10	28	0	1
13	20	2	4	35	0	1
14	39	10	20	40	0	0
15	61	110	17	28	0	0
16	61	179	14	30	0	1
17	62	51	11	6	0	1
18	67	26	25	21	0	1
19	40	14	6	15	0	0
20	67	116	11	15	0	0
21	21	5	6	32	0	0
22	61	47	15	28	0	0
23	58	135	18	36	0	0
24	43	22	12	24	0	0
25	67	147	19	30	0	0
26	35	7	8	35	0	1
27	67	137	25	7	0	0
28	46	32	20	14	0	0
29	39	5	6	21	0	0
30	43	55	14	16	0	0
Mean	49	64	13	22	0	0.27

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 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?

Analysis the Impact of logistical changes excluding the bad human behaviors

Table 4 summarizes the results of our multi-project simulation experiment. 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-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-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

Simulation results of PERT-AEAP, CCPM and PERT-ALAP

N = 1,000	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-AEAP	CCPM	PERT-ALAP	PERT-AEAP	CCPM	PERT-ALAP	PERT-AEAP	CCPM	PERT-ALAP	PERT-AEAP	CCPM	PERT-ALAP	PERT-AEAP	CCPM	PERT-ALAP	PERT-AEAP	CCPM	PERT-ALAP	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	86	86	86	142	162	162	170	204	202	99	102	99	166	202	202	204	261	259
90th percentile	92	91	92	156	162	163	170	198	197	103	102	103	169	182	182	190	222	222	123	124	123	203	227	230	231	285	284
(Estimated project time)	(87)	(90)	(87)	(137)	(158)	(137)	(162)	(192)	(162)	(97)	(100)	(97)	(153)	(176)	(153)	(181)	(214)	(181)	(114)	(137)	(114)	(179)	(241)	(179)	(212)	(293)	(212)
Reliability**	(80%)	(89%)	(80%)	(68%)	(86%)	(20%)	(70%)	(80%)	(5%)	(84%)	(89%)	(84%)	(75%)	(87%)	(30%)	(80%)	(80%)	(27%	(80%)	(97%)	(80%)	(70%)	(96%)	(13%)	(67%)	(95%)	(1%)
Mean	80	80	80	133	149	150	157	187	186	87	87	87	143	163	164	171	206	204	102	103	102	172	205	205	207	264	260
Standard deviation	9.92	9.09	9.92	17.15	13.17	14.59	13.41	13.82	13.92	13.91	13.57	13.91	19.78	19.08	19.56	15.24	13.83	13.21	18.33	16.34	18.33	24.98	24.78	21.03	19.30	17.41	19.46
t value	0.00		0.00	-23.40*		1.61	-49.27*		-1.61	0.00		0.00	-23.01*		1.16	-53.78*		-3.30*	-1.29		-1.29	-29.66*		0.00	-69.35*		-4.84*

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

**Reliability: Compared with the project plan results of Table 1.

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

1. 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. For multi-project execution, no matter whether the uncertainty is low, medium, or high, the results show that the PERT-AEAP significantly achieves better mean project duration than CCPM does in terms of projects B and C.

2. 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 three time estimates, optimistic, most likely, and pessimistic, 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 soon a completion date. The higher the uncertainty is, the worse the result will be.

3. Realistically, few project practitioners will use three time estimates (optimistic, most likely, and pessimistic) to estimate task time and project time. They typically take the 90th percentile of task distribution shown in Figure 7 as the task time (CPM, Critical Path Method). Table 5 illustrates that comparing with the CCPM and PERT, CPM yields a much longer project time and longer project completion date. This resulting that no matter whether uncertainty is low, medium, or high, projects planed with CPM can be completed with nearly 100% reliability. This means that directly taking the 90th percentile of task distribution of Figure 7 as the task time, the CPM plan will result in too conservative a plan, making it less competitive.

4. 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.

Table 5

Project plan reliability of CPM, PERT and CCPM

	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
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%

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

1. Concerning the project plan, CCPM logistical change can plan a higher reasonable and reliable project plan than the PERT and CPM methods because both either underestimates the project completion date (PERT) or overestimates CPM. 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 and CPM 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.

Conclusions

This study used games and simulation to overcome two obstacles blocking the implementation 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 *Project Management Body of Knowledge* (*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; Kapoor, 2009; Jacob and Mendenhall, 2008): (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.

References

Ashtiani, B., Jalali, G. R., Aryanezhad, M. B., Makui, A. (2007). A new approach for buffer sizing in Critical Chain scheduling. IEEE Conferences, Industrial Engineering and Engineering Management International Conference, Singapore, 1037-1041.

Cohen, I., Mandelbaum, A., and Shtub, A. (2004). Multi-Project scheduling and control: a process-based comparative study of the critical chain methodology and some alternatives. Project Management Journal, 35(2), 39-50.

Cui, N., Tian, W., and Bie, I. (2010). Rescheduling after inserting the buffer in the Critical Chain scheduling. IEEE Conferences, Logistics Systems and Intelligent Management International Conference, Harbin, 2, 1105-1110.

Drucker, P. F. (1985) Innovation and entrepreneurship. William Heinemann Ltd, England.

Duncan, W. R. (1999). Back to basics: charters, chains, and challenges. PM Network. Project Management Institute.

Elmaghraby, E., Herroelen, W. S., And Leus, R. (2003). Note on the paper 'Resource-constrained project management using enhanced theory of constraint' by Wei *et al*. International Journal of Project Management, 21, 301-305.

Goldratt, E. M. (1997a). Critical Chain. The North River Press Publishing Corporation, Great Barrington.

Goldratt, E. M. (1997b). Project Management the TOC Way. The North River Press Publishing Corporation, Great Barrington.

Goldratt, E. M., and Goldratt, A. R. (2003). TOC Insights-Project Management and Engineering. http://www.toc-goldratt.com/store/product.php?productid=16273, Accessed March 20, 2010.

Goldratt, E. M. (2008) Standing on the shoulders of giants-production concepts versus production applications. TOCICO International Conference, Las Vegas, Nevada.

Goldratt, E. M. (2009). The Strategy and Tactic Tree for Projects. https://tocico.site-ym.com /default.asp?page=s_and_t, Accessed March 20, 2010.

Goldratt Marketing Group. (2011). http://www.toc-goldratt.com

Herroelen, W., and Leus, R. (2001). On the merits and pitfalls of critical chain scheduling. Journal of Operations Management, 19 (5), 559-577.

Herroelen, W., Leus, R., and Demeulemeeter, E. (2002) Critical chain project scheduling: Do not oversimplify. Project Management Journal, 33(4), 48-60.

Jacob, D., and Mendenhall, B. (2008) Project Management in a Lean World. TOCICO International Conference, Las Vegas, Nevada.

Kapoor, A. (2009). Why Lean doesn't work. Execution Management Minute Realization Company, USA.

Leach, L. P. (1999). Critical Chain Project Management improves project performance. Project Management Journal, 30(2), 39-51.

Leach, L. P. (2004). Critical Chain Project Management. Artech House Publishers.

Liu, J. B., and Xie, J. H. (2008). Critical Chain Project Management based heuristic algorithm for multiple resources-constrained project. IEEE Conferences, Business and Information Management International Seminar, Wuhan, China, 1, 330-335.

Long, L. D., and Ohsato, A. (2007). Solving the Resource-Constrained project scheduling problem by Genetic Algorithm. Journal of Japan Industrial Management Association, 57(6), 520-529.

Long, L. D., and Ohsato, A. (2008). Fuzzy critical chain method for project scheduling under resource constraints and uncertainty. International Journal of Project Management, 26(6), 688-698.

Newbold, R. C. (1998). Project Management in the Fast Lane-Applying the Theory of Constrains. The St. Lucie Press, Boca Raton.

Newbold, R. C. (2008). The Billion Dollar Solution—Secrets of PROCHAIN Project Management. ProChain Press, Lake Ridge, VA.

ProChain Solutions Inc. (2011). http://www.prochain.com

PMBOK. (2004). Project management body of knowledge. PMI (Project Management Institute), PMI Press, Pennsylvania.

Rand, G. K. (2000). Critical chain: the theory of constraints applied to project management. International Journal of Project Management, 18(3), 173-177.

Realization Technologies Inc. (2011). Resource Library. http://www.realization.com /resource-library.html#casestudies, Accessed March 20, 2011.

Rezaie, K., Manouchehrabadi, B., and Shirkouhi, S. N. (2009). Duration estimation, a new approach in Critical chain scheduling. IEEE Conferences, Modelling & Simulation, Third Asia International Conference, Bali, 481-484.

Steyn, H. (2000). An investigation into the fundamentals of critical chain project scheduling. International Journal of Project Management, 19(6), 363-369.

Steyn, H. (2002). Project management applications of the theory of constraints beyond critical chain scheduling. International Journal of Project Management, 20(1), 75-80.

Trietsch, D. (2005). Why a critical path by any other name would smell less sweet? Towards a holistic approach to PERT/CPM. Project Management Journal, 36(1), 27-36.

Yuji, K. (2010). WA: Transformation management by harmony. Croton-Hudson, North River Press, New York.

Zhao, Z. Y., You, W. Y., and Zuo, J. (2010). Application of innovative critical chain method for project planning and control under resource constraints and uncertainty. Journal of Construction Engineering and Management, 136(9), 1056-1060.