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A Comparative Study of the Critical Chain and PERT Planning Methods: No Bad Human Behaviors Involved

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Abstract

Since 1997, Critical Chain Project Management (CCPM) method has received a lot of attention and hundreds of successful cases have also been reported and all claims that it is possible to rapidly achieve highly reliable on-time delivery (OTD) with short project lead time (PLT) in multi-project environment. The main reason that CCPM can achieve highly reliable OTD and short PLT in multi-project environment can be contributed to that CCPM makes good use of safety time imbedded in tasks by two changes: logistical change and bad human behaviors change. However, if no bad human behaviors involved, does the mere emphasis on logistical change contributed to the success of project time reduction and OTD improvement? This is the key question still remained. A comparative study of the critical chain and Program Evaluation and Review Technique (PERT) planning methods, no bad human behaviors involved, was performed in this study. The simulation results showed that in terms of mean project time, CCPM is no significantly better than PERT. However, in terms of plan reliability, CCPM achieve higher reliable than PERT did and this is the contribution of CCPM logistical change.

Keywords: Critical Chain Project Management, On-time delivery, Project lead time

1. Introduction

Since 1997, Goldratt first published his novel, Critical Chain book (Goldratt, 1997a), proposed the Critical Chain Project Management (CCPM) 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 to project management in multi-project environment. In the past 15 years, many project management practitioners and researchers wrote books (Goldratt and Goldratt, 2003; Leach, 1999; Newbold, 1998/2008; PMBOK, 2004), developed software systems (Realization, 2012) to support CCPM implementation and created implementation strategy and tactics to guide practitioners how to implement CCPM (Goldratt and Goldratt, 2003; Goldratt Consulting, 2008). In addition to the knowledge development, hundreds of successful cases have also been reported and all claims that it is possible to rapidly achieve highly reliable on-time delivery (OTD) with short project lead time (PLT) in multi-project environment (Bregman, 2009; Realization, 2012). However, in spite of the articles are praising the approach, still some are criticizing it. Two major critics, one is the shortcomings of CCPM the other is the ideas of CCPM are not new.

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 *et al.*, 2007; Liu and Xie, 2008; Long and Ohsato, 2008; Kuo *et al*., 2009), critical chain identification (Long and Ohsato, 2007; Bevilacqua *et al.*, 2009; Cui *et al.*, 2010; Zhao *et al.,* 2010) and priority control (Cohen *et al.*, 2004). New methods were developed and the validity of the proposed methods were tested, results shows that the proposed methods yields schedules which are more reliable than the schedules produced by original CCPM method of duration estimation and priority control. By answering this critic, Goldratt (1997a/1997b), Rand (2000) and Steyn (2000, 2002) emphasizes that due to uncertainty and unavailability of accurate data on task duration, to optimize buffer size, critical chain schedule and priority control is a myth, the key is the way to manage uncertainty—buffer management. However, from the academic research viewpoint, those research efforts to enhance the theory of CCPM method.

About the second critic, Duncan (1999) criticized that although CCPM presents some good ideas as new insights but that these ideas are not new. He also doubts whether it has much to offer if we are applying the PMBOK (2004) concepts properly. He also claims that reducing bad multi-task is well documented in the project management literature. Herroelen and Leus (2001, 2005) and Herroelen *et al.* (2002) point that determines project make span with critical chain concept is also not new because as early as 1964, Wiest (1964) already introduced the concept of a critical sequence "determined not by just the technological ordering and the set of job time, but also by resource constraints; furthermore, it is also a function of a given feasible schedule".

Steyn (2000, 2002) in his study mentioned that Drucker (1985) says that a great deal of new method is not new knowledge. Innovation is a new perception. It is putting together things that no one has thought of putting together before, things that by themselves have been around a long time. His study concluded that CCPM puts together concepts that have not been put together in the same way before and is therefore considered an innovation. His study presents that the main reason that CCPM can achieve highly reliable OTD and short PLT in multi-project environment can be contributed to that CCPM makes good use of safety time imbedded in tasks by two changes: logistical change (aggregation in his paper and performed by applying CCPM "Critical chain planning and buffering" method) and bad human behaviors change. His study pointed out that the assumptions regarding bad human behaviors are not critical to the validity of CCPM. However, Leach (1999) indicated although CCPM has been applied, project duration reduced and OTD increased successfully, it is still difficult to determine, for example, to what extent the CCPM or the mere emphasis on logistical change (network planning) contributed to the success.

Does the mere emphasis on logistical change contributed to the success of project time reduction and OTD improvement? This is our research interesting. A comparative study of the critical chain and Program Evaluation and Review Technique (PERT) planning methods, no bad human behaviors involved, will be performed in this study. Since the ways of planning (project time estimation) and execution will affect the success of project time reduction and OTD improvement, so we will first compare CCPM method with PERT method to evaluate what is the difference of the planning results done by two methods under same project networks and uncertainties. Second, we will perform simulation to execute both plans to evaluate OTD performance under different scheduling rules. Both single project and multi-project will be evaluated. The rest of the study is organized as follows: In the next section, we review how the behavior and logistical changes of CCPM. Then we perform project plan with CCPM and PERT methods and compare the planed results done by the two methods. Project execution done by simulation is then performed to evaluate mean project time and OTD performance under different scheduling rules. We then conclude with results finding.

2. The fundamental changes of CCPM

The main reason that CCPM can achieve highly reliable OTD and short PLT in multi-project environment can be attributed to that CCPM makes good use of safety time imbedded in tasks by two changes: logistical change and human behaviors change.

2.1 Logistical change

The logistical changes were performed by applying CCPM “Critical chain planning and buffering” method. In CCPM, it is claimed that safety time embedded at the task level prolongs the project without providing sufficient safety to the project completion, and tends to promote negative human behavior and bad multi-tasking. The greater the degree of the 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 also requires much less safety than the sum of safeties removed from the tasks. To encourage resources working on “aggressive but possible” task time requires that resources no longer be judged by their ability to meet their time estimates, this further requires performance measurement change. In other words resource must recognizes that, except for the project due date, the schedule indicates targets or expected durations rather than commitments or milestone. CCPM “Critical chain planning and buffering” method consists of two major steps: (1) Building critical chain plan for each single project from its project network and (2) staggering projects.

The steps involved in building critical chain plans from project network are: (1) Lay out everything for the project network-push as late as possible, to determine where resource contention may fall; (2) Deconflict contention; (3) Identify critical chains—the longest task and resource dependency path; (4) Insert project buffer—one half of the safety removed from the critical chain path; (5) Insert feeding buffer—everywhere a non-critical chain path or task dependency exists also requires a feeding buffer.

The steps involved in staggering projects are (1) select the resource which is the highest load and (2) the projects were staggered according to the highest loaded resource to determine the starting time of the first task of each path of the projects and projects deliver date. Due to the fact that time estimates had been cut in half, one of the elements important in staggering projects properly was to ensure enough staggering caused by the schedule of the "highest loaded resource" (CCPM call it drum schedule) to minimize peak loads on the other resources (which may have been 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. CCPM utilized up to 100% of the safety that was formerly in the drum task estimates and reallocated the safety to the synchronization buffer.

2.2 Human behaviors change

Uncertainty is the nature of the project's task. People know from experience that safety is necessary to protect the due-date and to avoid letting other people down. However, how 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 are approaching the deadline, they go and cram to make the deadline. This is so-called student syndrome (delay the starting time so lengthening the duration time). To make matters worse, there is a phenomenon called Parkinson's Law that people will always use the given time such as not report early finishes and work expands to fill the available capacity. Both behaviors cause the safety time to be misused and masked. Misusing (or wasting) safety time leads to missed commitments. Furthermore, in multi-project environment, releasing projects too early causes too many projects to be executed simultaneously. This means that many resources find themselves under pressure to work on more than one task at a time, in which case multi-tasking is unavoidable. Prolific bad multi-tasking drastically increases the lead time of tasks and of projects, which leads to further missed commitments. Also, the lack of clear priorities combined with the fear that projects will not be finished on time also leads to multi-tasking.

To avoid these three bad human behaviors, CCPM advocates that the logistical change, aligned with performance measurement change and buffer management, good behaviors become more desirable (Yuji, 2010). For example, giving people "aggressive but possible" task duration and judging people no longer their ability to meet their time estimates, student syndrome and Parkinson's Law can be reduced. Also, giving people "aggressive but possible" task duration, people 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 can be reduced in both situations. Logistical change also staggers each project as late as possible but with synchronization buffer and schedules non-critical chain as late as possible but with feeding buffer. Both also can reduce multi-tasking behavior. Multi-tasking can be further avoided if a resource is switched between tasks only when a project buffer has been eroded to the extent that it poses a risk of delaying project. This can be achieved that priorities should be set only according to the degree the task is consuming from its project (or feeding) buffer. Buffer management of CCPM is the way to determine the priority of a task by examining its impact on the completion of the project. Bendoly and Swink (2007) also support that lack of timely information impact the behaviors of project managers in ways that do not directly focus on work objectives but nevertheless affect performance.

3. Project Planning: CCPM vs. PERT

Figure 1 illustrates a multi-project environment involved three similar single project network (A, B, and C) adopted from PMsim (Goldratt, 1997b). Each project network is layout as late as possible and without leveling resources contention. Each project network consisted of several paths, 20 tasks involving 10 types of resources (engineers). Because each type of resource had only one engineer, they all had to work on these three projects. All tasks required the same amount of time and were subject to the same uncertainty, which made it considerably easier to track the progress of the project. Although this was far from realistic, it did not prevent us from drawing realistic conclusions. Three different task uncertainties low, medium and high (shown in Figure 2) were analyzed in this study.

3.1 Single project plan

Figure 3a illustrates the critical chain plan of project A (with uncertainty medium) done by the CCPM “Critical chain planning and buffering” method. Critical chain method directly takes 90th percentile of task distribution of Figure 2 as the estimated task time. Cutting the estimated tasks time into half but with aggregated project buffer inserted at the end of critical chain path and feeding buffer placed where non-critical chain path feed 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.

Figures 3b shows the project plan of project A done by the traditional PERT method. The non-critical path is planned as early as possible—full use of float. Notice that some paths such as C1-R, E1-B and I1-R cannot be start earlier because limited by resources and task dependence. Concerning the expected task time and project time estimation, PERT does not directly take 90th percentile of task distribution of Figure 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:

$$\text{Expected task time} = (\text{Optimistic time estimate} + 4\times\text{Most likely time estimate} + \text{Pessimistic time estimate})/6 \qquad (1)$$

$$\text{Standard deviation} = (\text{Pessimistic time estimate} - \text{Optimistic time estimate})/6 \qquad (2)$$

Since the longest path consists of 7 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 tasks time of longest path + Square root of sum of the Variances of the tasks on the longest path × 1.3) (3)

Where, 1.3 is Z value of normal distribution with 90% confidence level.

For Project A, based on the expected project time equation, with the task time distribution of uncertainty medium (Figure 2b), the expected task time is equal to 11.8 days ((3+4×10+28)/6), standard deviation is 4.17 days ((28 - 3)/6). So the expected project duration is 97 days ((11.8×7 + (square root of 7×4.17×4.17) ×1.3)). Table 1 shows the planned results that CCPM give longer expected project time than PERT, the higher uncertainty the bigger the difference.

3.2 Multi-project plan

Figure 4a illustrates the multi-project plan of the three single projects of Figure 1 done by CCPM multi-project plan method. Critical chain of each project was planned with 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. CCPM multi-project plan method add synchronization buffer to prevent projects being released too early (release project as late as possible). Figure 4b shows the multi-project plan of the same three single projects done by PERT method. Critical path of each project is planned with PERT method. PERT does not adding synchronization time buffer to the schedule of the highest loaded resource among projects. Table 2 shows that the completion date of project B and C planned by CCPM are longer than those planned by PERT method. The main difference is due to the planned method of single project and with and without synchronization buffer.

4. 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 (1997b). Each simulation was replicated 1,000 times. Computer will randomly generate task duration time for each task based on the task time distribution as shown in Figure 2. Data collected are mean project duration, its standard deviation, medium and 90th percentile. No bad human behaviors such as bad-multi-task, student syndrome, Parkinson's Law exist.

4.1 Single project simulation

Since CCPM plan non-critical chain path to start as late as possible and do not encourage to start early even if it can be started, 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). For the PERT method, the simulation was designed in two ways, one is to start the first task of each path immediately when it can be started (we call it PERT-SP-AEAP), the other is same as CCPM to start 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 3 summarizes the results of our single project simulation. From the statistical hypothesis test of the population mean by student’s t-test, no matter the uncertainty is low, medium or high, the data show that the CCPM significantly achieved better mean project time than PERT-SP-ALAP did. However, from the statistical hypothesis test of the population mean by student’s t-test, no matter the uncertainty is low, medium or high; the data show that the CCPM is no significantly better than the PERT-SP-AEAP in achieving mean project time. Concerning the planned reliability, CCPM achieve higher reliable than both PERT-SP-AEAP and PERT-SP-ALAP did.

4.2 Multi-project execution

Since CCPM plan method added synchronization buffer to prevent projects being released too early (do not encourage to start project early even if it can be started), therefore, the simulation was designed according to the scheduling rule which the first task of each path of each project will be started 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 (from Table 3 shown PERT-SP-AEAP got better result). However, the scheduling rule among projects was designed in two ways, one is same as the CCPM (we call it PERT-MP-ALAP). The other is that except the tasks of B1-B, G1-R and H1-P of the first project will be started as the planned start time, the rest of tasks of all projects will be started immediately when it can be started (we call it PERT-MP-AEAP).

From the statistical hypothesis test of the population mean by student’s t-test, no matter the uncertainty is low, medium or high, the data show that the CCPM has no significantly better than PERT-MP-ALAP. However, the statistical hypothesis test of the population mean by student’s t-test, no matter the uncertainty is low, medium or high; the data show that the PERT-MP-AEAP significantly achieves better mean project duration than CCPM in terms of projects B and C. Concerning the plan reliability, CCPM demonstrated higher reliable than PERT. The higher uncertainty the better planned result of CCPM did.

4.3 Results finding

From the project plan and execution results, if bad human behaviors were excluded, we can draw several findings as follows:

1. No matter for single project plan or multi-project plan, with 90% of confidence level, CCPM plan is much conservative (longer project time and longer project completion date) than PERT plan. The higher uncertainty the higher conservative is.
2. For single project execution, no matter the uncertainty is low, medium or high; the results show that the CCPM is no significantly better than the PERT-SP-AEAP in achieving mean project duration. Further for multi-project execution, no matter the uncertainty is low,

medium or high; the results show that the PERT-MP-AEAP significantly achieves better mean project duration than CCPM in terms of projects B and C.

3. Although from the mean project time result, CCPM is no better than PERT, however, from the plan reliability, no matter the uncertainty is low, medium or high; the simulation result shows that CCPM achieves higher reliable. This means by using the Equation (3) to estimate the project duration time and no adding synchronization time buffer to the schedule of the highest loaded resource among projects like CCPM did, PERT given too short project duration time and too tight completion date. The higher uncertainty the worse will be.
4. We all know, in reality, seldom of project practitioners will use Equation (3) to estimate task time and project time. They usually directly take 90th percentile of task distribution of Figure 2 as the task time. By taking this way and re-plan the project with PERT plan method. Comparing with CCPM and PERT plan with the project time estimate of equation (3), much longer project time and longer project completion date were got. Comparing the planned results with the simulation results of Table 3, no matter the uncertainty is low, medium or high; projects can be completed almost 100% reliable. This means if by directly taking 90th percentile of task distribution of Figure 2 as the task time, PERT plan will result too conservative plan which means less competitive.
5. From the simulation, we learn that if bad human behaviors were excluded, the expected task time estimation method, schedule rule (within project and between projects) and task time distribution are the three major factors impact the result of both methods.

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

1. Concerning the project plan, CCPM logistical change can plan higher reasonable and reliable project plan than PERT method. PERT either underestimate project completion date (by using Equation (3)) or overestimate (by directly taking 90th percentile of task distribution of Figure 2 as the estimated task time). Simulation results support that no matter the uncertainty is low, medium or high; CCPM gives higher reasonable and reliable project plan. This is the contribution of the CCPM logistical change.
2. The scheduling rule used by CCPM is as late as possible (within project and between projects). Scheduling non-critical path and projects as late as possible has its advantages such as delay cost incur, avoiding bad multi-tasking, etc, however, with PERT plan, scheduling non-critical path and projects as late as possible will have high chance to cause project being delay because no safety buffer to handle uncertainty (simulation results support this point), so schedule as early as possible is always preferable. CCPM with project and feeding buffers can tell when not to start and will not hurt project being delay. This is also the contribution of CCPM logistical change.

5. Conclusion

In this study, our interesting is to see if no bad human behaviors involved, does the mere emphasis on logistical change contributed to the success of project time reduction and OTD improvement? A comparative study of the critical chain and PERT planning methods, no bad human behaviors involved, was performed in this study. By taking a three-project environment, planned them with CCPM and PERT method, executed the plans by simulation. The results showed that in terms of mean project time, CCPM is no significantly better than PERT-AEAP. However, in terms of plan reliability, CCPM achieve better than PERT-AEAP. This is due to CCPM logistical change generates much reasonable and higher reliable project plan than PERT method. The CCPM with project and feeding buffers can tell when not to start and will not hurt project being delay. We all know in reality, assuming no bad human behaviors exist is impractical. Goldratt’s study (1997a/1997b) proved that if bad human behaviors are added into the simulation, the results showed that even if taking 90th percentile of task distribution of Figure 2 as the estimated task time, the OTD is not 100% reliable, instead the OTD is very poor. However, the point is whether bad human behaviors exist or not, but how to reduce them. Goldratt believe that CCPM logistical change is one of the best ways to reduce bad human behaviors and this worth for further research to either validate or invalidate his claim.

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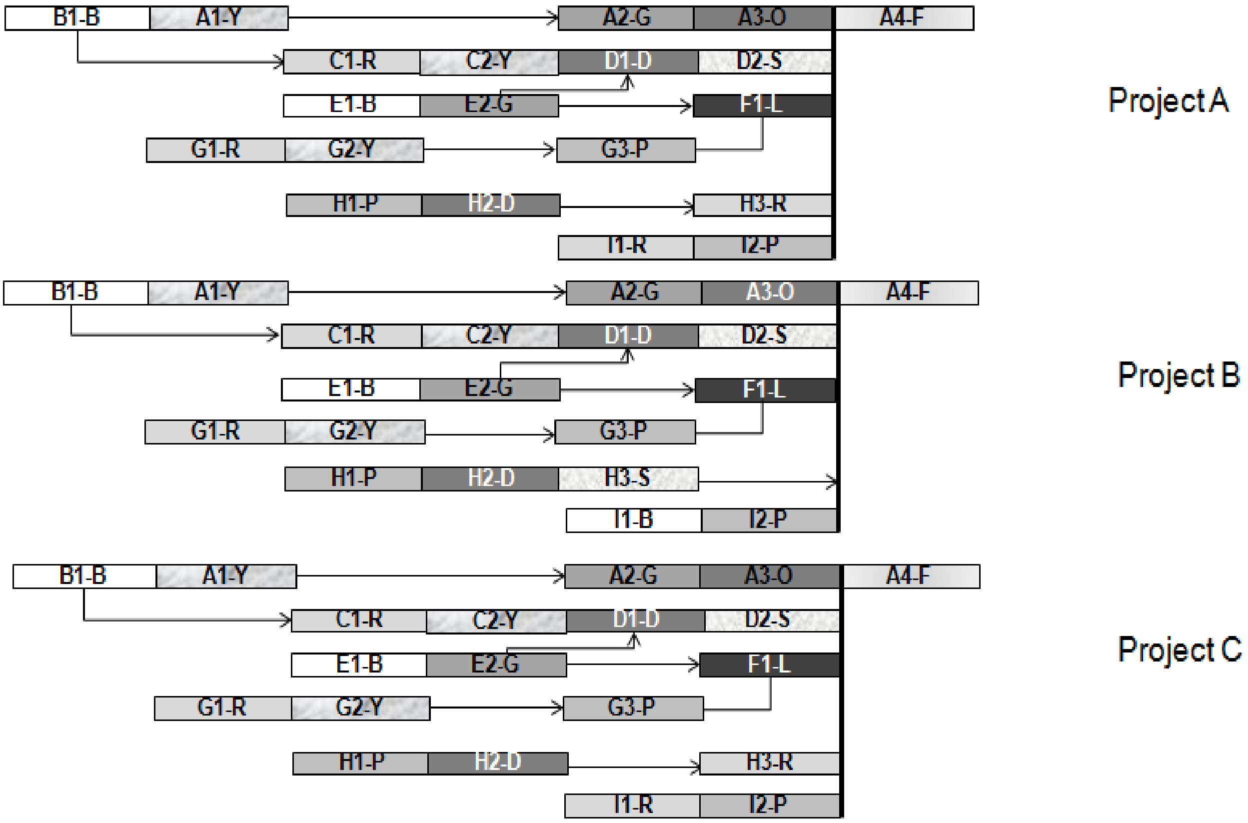
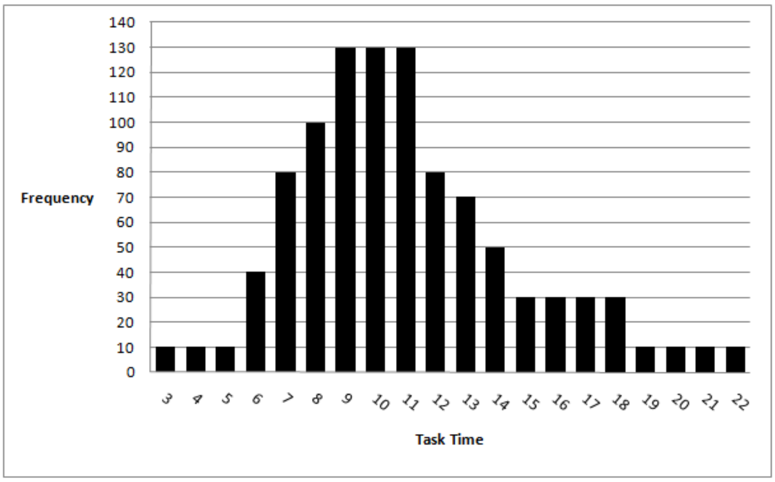
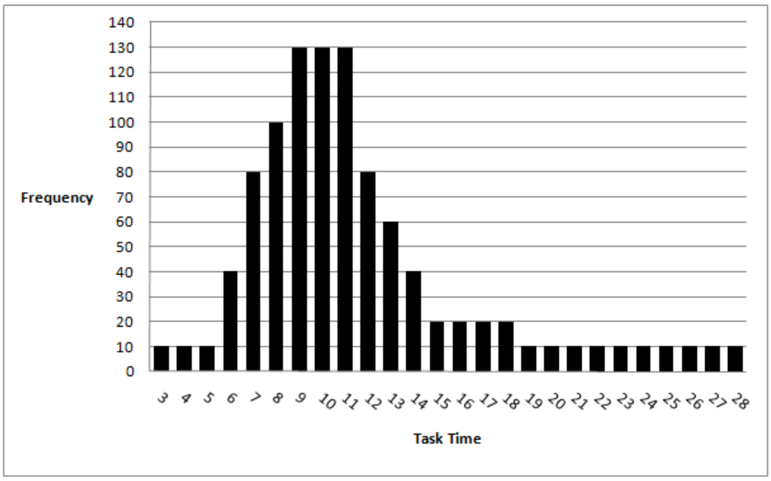


-Y: Yellow -G: Green -O: Orange -F: Fluorescent Green -B: Blue
-R: Red -D: Deep Purple -S: Silver -L: Light Green -P: Pink

Figure 1 Multi-Project environment involved three similar single project network



(a)



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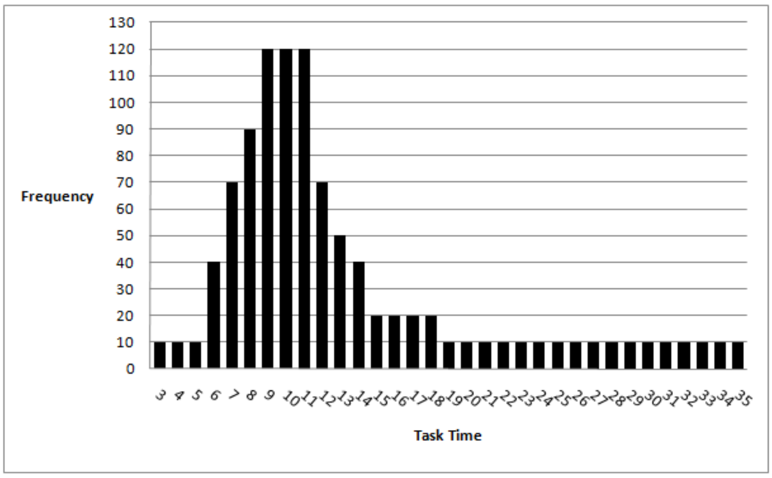

(c)

Figure 2 Theoretical estimated task time distribution with three different task uncertainties, low, medium and high. (a) Uncertainty low; (b) Uncertainty medium; (c) Uncertainty high

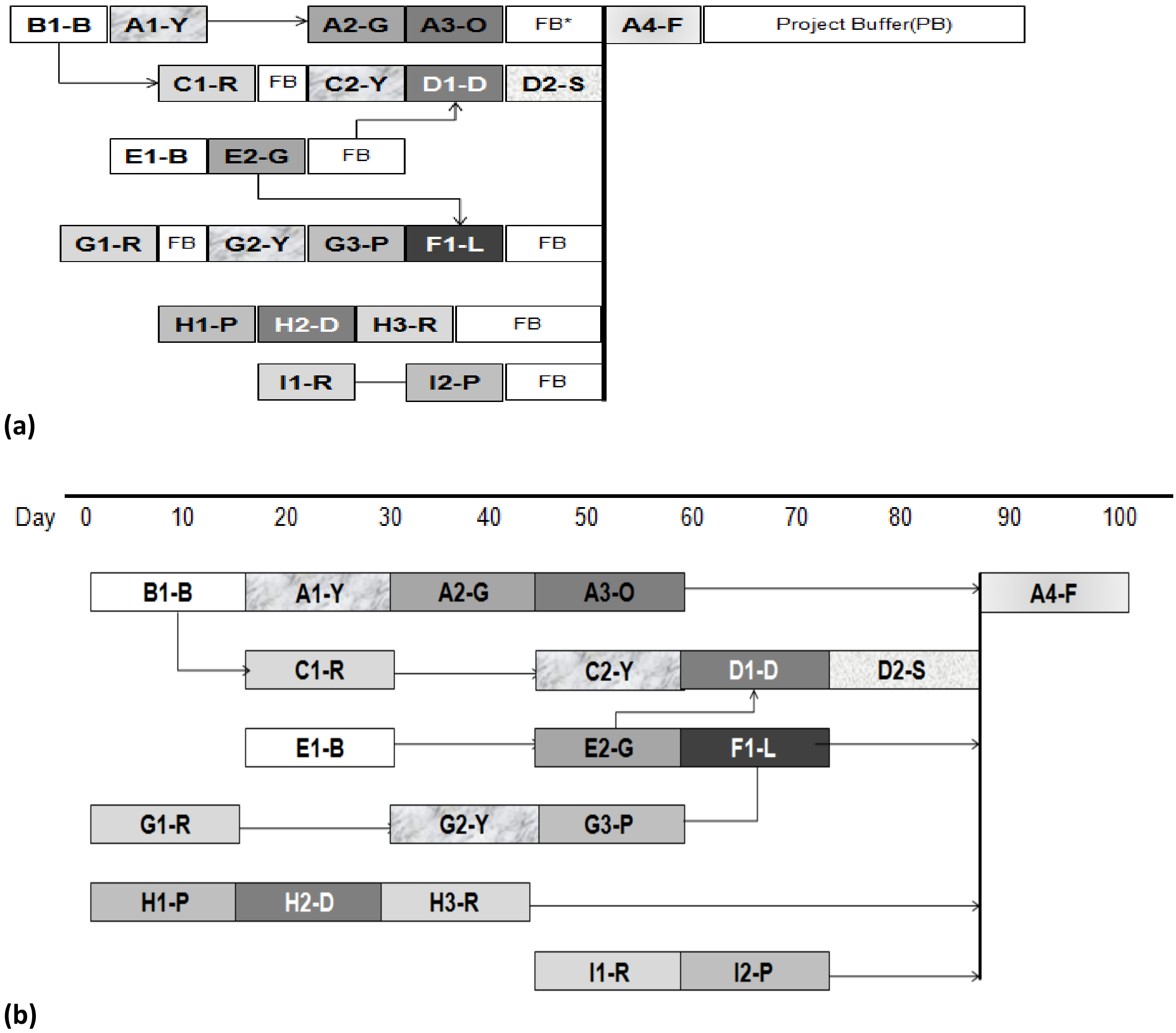

Figure 3 Single-Project CCPM/PERT-AEAP with uncertainty medium

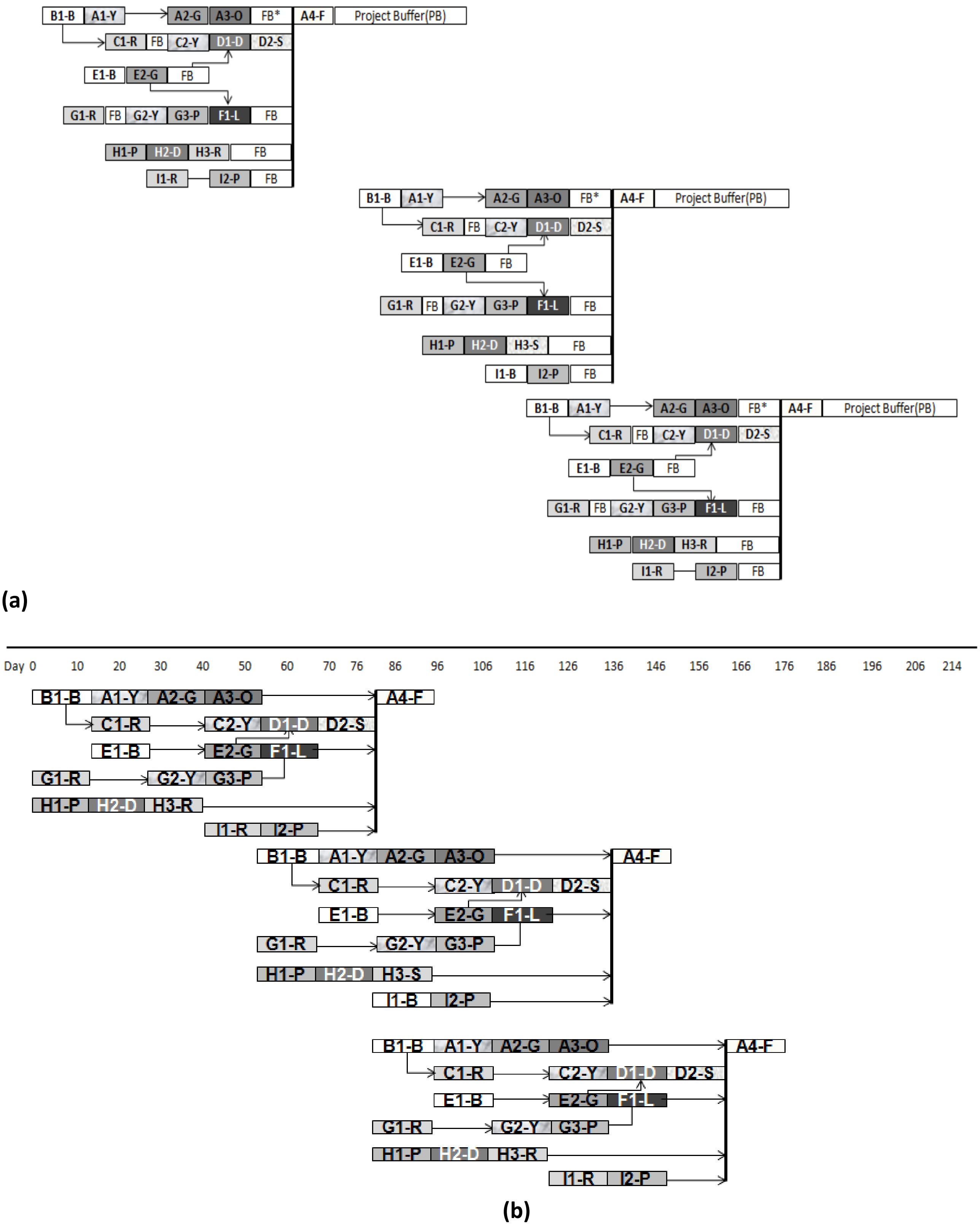

Figure 4 Multi-Project CCPM/PERT-AEAP with uncertainty medium

Table 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

Table 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

Table 3 Simulation results of single project

N= 1,000	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 $[t_{0.05}(\infty) = 1.645]$