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Critical Chain Project Management Theory and Practice

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ABSTRACT

It is now over 10 years since the first publication on Critical Chain Project Management (CCPM) (Goldratt, 1997) and since then software and implementation practice has rapidly developed. The logic and assumptions underpinning this new knowledge has recently been published (Goldratt, 2007) in the form of a strategy and tactics (S&T) tree. It is, therefore, timely to review the CCPM claims from both a theoretical and practical perspective in the light of this new guidance. The paper includes interim findings of longitudinal case research of a construction company following the S&T logic to implement CCPM.

The paper, firstly, provides an overview of CCPM in the light of prior publications before reviewing the newly published implementation guidance and evidence of current industrial practice - this includes the use of CCPM within a government construction project initiative in Japan. Secondly, the case research methodology applied to a construction company is presented followed by the interim results and findings. Finally, the interim case findings are evaluated in the light of prior research and the wider theoretical links.

The paper concludes that CCPM is now making a significant contribution to improving project management performance worldwide. The S&T guide provides a more comprehensive implementation methodology as well as updated thinking on how CCPM should be implemented - particularly in relation to flow control and continuous improvement. The research findings are only interim, but largely support the logic within the S&T implementation guide with minor reservations. However, the study, thus far, does not include the flow planning of multiple projects. Further research is clearly needed to test the guidance in more detail as well as clarify the relationship between lean and TOC concepts with particular reference to flow control and continuous improvement.

INTRODUCTION

Theory in operations has undergone significant change in the past 40 years with a shift from an economics cost based view to one emphasising flow and the reduction of waste and variation in delivery systems (Ohno, 1988; Deming, 1982; Womack et al., 1990). This has, however, not been so evident within the largely separate field of project management. The underlying theoretical basis for project planning and control has not significantly changed in over 50 years, even though the planning and control tools, such as network planning have long been acknowledged to be ineffective in practice (Fondahl, 1980).

‘All too often, however, only the original plan and scheduling data are ever produced. They continue to cover the office wall long after they are obsolete and bear little resemblance to the current progress of the job.’

CCPM under the umbrella of TOC has been presented as an answer to this weakness but lean protagonists would make similar claims. Koskela & Ballard (2006), with reference to construction projects, argue project management theory needs to mirror the transition in thinking experienced in production operations. They advocate changing from an economics based transformation model to a flow model, as adopted by Toyota and now associated with lean. They advocate adopting practices to manage a flow routine and encouraging local control to improve synchronisation, seeing this as a natural extension of lean practices. However, although the direction of improvement is clear, means of developing formal planning and control tools to accommodate the uncertain project environment is not apparent.

Goldratt (2007) claims the TOC versus lean debate is a false dichotomy and that TOC encompasses the same underlying concepts of flow and continuous improvement associated

with the Toyota Production System (TPS) (Ohno, 1988). However, he and others asserts TOC adds value by offering thinking processes (Goldratt, 2008) that support the development of applications for different environments, as in the case of projects. More specifically, Goldratt (1997, 2007) claims CCPM is a means of applying the principles of flow and continuous improvement to a project environment. Leach (1999) and others have previously emphasised this link by arguing that CCPM is an extension of Shewhart's (1939) continuous improvement concepts and Ohno's (1988) TPS flow concept.

In reviewing the 10 years of development of CCPM and the case research findings this paper tries to look beyond the more evident practical benefits to the underlying conceptual assumptions and theoretical links with lean production.

The paper is structured as follows:

- Overview key features of CCPM with reference to prior publications, newly published implementation guidance and industrial practice - including the Japanese Ministry of Infrastructure, Transport and Tourism construction initiative.
- Present the case research method and interim research findings of a UK construction company's ongoing longitudinal case, utilising Goldratt's S&T guide and Concerto software.
- Discuss and conclude on the findings in the light of prior research and a wider theoretical framework that links TOC and lean concepts.

CCPM REVIEW: OUTLINE, LITERATURE, PRACTICE AND GUIDANCE

This section sets the scene by outlining the core elements of CCPM before reviewing critical literature, evaluating recorded practice and outlining the recently published implementation guide (Goldratt, 2007).

CCPM in outline

A central driver for adopting CCPM is enabling more predictable and shorter project lead times. The argument being that this will not only enhance time related order winning criteria but also reduce cost and improve adherence to specification. To achieve this the focus is on improving the flow of projects using similar logic to that of lean manufacturing and the operations based TOC application entitled Drum-Buffer-Rope (Schrageheim and Detmer, 2001).

The main conceptual elements of CCPM are presented below in the context of planning, execution and continuous improvement together with the distinctions with conventional project management.

Project planning

- CCPM takes account of resource as well as precedence dependencies in determining the project duration – this is termed the critical chain. In Figure 1 the critical path would be denoted by activities 1-3-4 whereas in CC it is denoted by 1-3-2-4 due to common resource B. In such cases the critical chain is shown to be longer than the critical path and all four activities need to be managed accordingly.
- CCPM introduces the concept of project and feeder time buffers to accommodate the effective management of buffer time that is commonly wasted when managed locally at the activity level. The project buffer is located at the end of the project to protect the critical chain and feeder buffers isolate activity sequences with float from the critical chain (see Fig.1). Thus, such buffers enable aggregation of the buffer time as well as better control, enabling both shorter and more controllable lead times.

In establishing these buffers the proposed start point is to halve existing activity times and put half of the remainder into the aggregated buffer, therefore, the buffer is equal to a third of the activity and buffer combination (see Fig. 1 for illustration).

- When planning in a multi- project environment CCPM advocates staggering the release of projects around a designated resource that acts as a drum. This is used to ensure flow and avoid too many open projects that result in excessive multi-tasking and missed due dates.

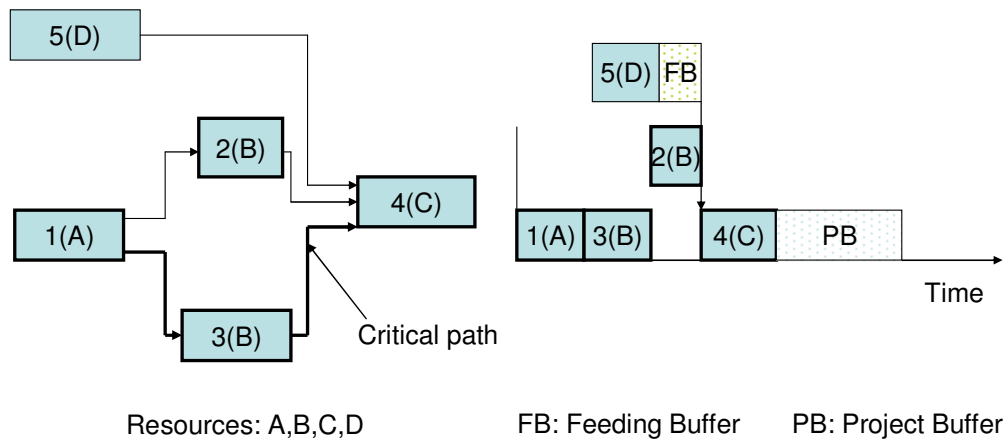


Figure 1 Network diagram and critical chain schedule showing buffers

Project execution and continuous improvement

- Task completion reporting

It is common practice for activity times to be reported in terms of work done, an economic measure that is often only formally reported weekly or even monthly. With CCPM the remaining time to complete the activity is reported on a much more frequent basis – ideally daily.

- Provide visibility of upcoming tasks

As there are no intermediate task dates in the planning system the task time remaining data provides advanced notice of upcoming tasks (this was previously been referred to as a resource buffer).

- Current and upcoming tasks are monitored in line with priorities to ensure tasks are effectively progressing.

In the more complex multi-project environment there are many in-progress tasks competing for a resource provider's time. In CCPM they are prioritised in terms of the ratio of critical chain completion and buffer consumption, commonly using green, yellow and red priority colour codes. Upcoming tasks are also displayed indicating their relative priority as well as the projected time when these tasks are expected to become available to that resource.

- 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 programme recovery.

- Reasons for delay are monitored and provide focus for improvement.

The relevant reasons for delay are extracted to focus improvement activity.

Review of literature

Much of the literature relating to CCPM is positive but the focus here is on the more critical sources in an attempt to expose underlying weaknesses that may be tested in the subsequent research. The main issues raised have been categorised as follows.

Originality

The main distinction between CCPM and traditional project management is well reported (Newbold, 1998; Leach, 1999; Umble and Umble, 2000; Steyn, 2001), however, there are questions over whether elements of the design are original to Goldratt. Trietsch (2005) is most critical in this area and goes into some detail on the elements of the approach he would attribute to others:

- This includes 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.
- 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 due dates had on traditional batch manufacture.
- 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 O'Brien’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).

Oversimplification

It is clear that Goldratt's (1997) original publication was focused on presenting a radically different conceptual approach that lacked detail, as in the case of the management of multi-projects highlighted by Elton and Roe (1998). Several authors (Raz et al., 2003; Elton and Roe, 1998) 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 organisations 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 does not concur with this assertion.

Paradigm change / over complication

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. They suggest a CCPM-lite version that would not have feeder buffers (p56). It is interesting to note that in healthcare patient flow such a variant has been developed (Umble and Umble, 2006) but this complexity argument is explored in this research in a more traditional project environments.

Raz et al. (2003) also argues that the software and training cost resulting from the need for a change in the organisational 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.

Pipeline scheduling

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 synchronisation (2007). It is intended that this new development will be closely investigated through this research if the opportunity arises.

Buffer sizing

The introduction of buffers is generally seen as a positive step in providing a means of managing uncertainty and with this acknowledging the need to not attempt to set intermediate task start and end dates (Deming, 1982). 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.

Conclusion

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.

Goldratt's Strategy and Tactic (S&T) tree implementation guide

The original publication presenting CCPM (Goldratt, 1997) addressed the main elements of the overall design but many of the details had to be worked out and refined in practice, as in the case of staggering multi-projects (Goldratt, 2007). The S&T guide to CCPM implementation has clearly been created with close reference to the implementation experiences of CCPM providers, such as Realisation. This knowledge has been provided in an innovative format that communicates the implementation process and logic in a way that links strategy and tactics with increasing levels of detail (see Figure 2).

The part of this tree that concerns the core elements of CCPM is the focus of the research that follows which particularly centres on the 'Build' and 'Sustain' elements.

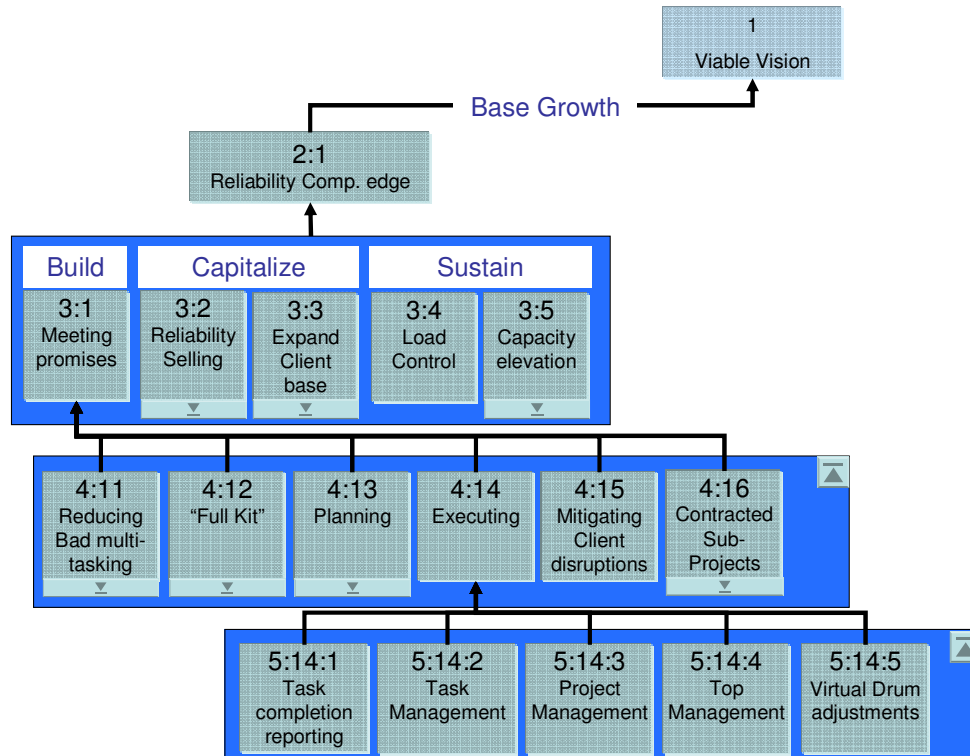


Figure 2 Extract of the CCPM S&T Tree breakdown

The implementation process embodied in these steps provides both wider and deep guidance on a sequential implementation process, which is briefly outlined below. Earlier published material on implementing CCPM was much less comprehensive and generally limited to 4:13 and 4:14 for which an outline is provided below.

- 3.1 *Meet Promises*

- 4:11 *Reducing bad multitasking*

Immediately reduce the number of live projects by 25% to reduce multitasking and improve flow.

- 4:12 *"Full kit"*

Utilising released capacity in 4:11 to ensure all projects are fully prepared before release.

- 4:13 *Planning*

Plan projects using CC networks, buffers and staggering.

- 4:14 *Executing*

Task reporting and management at task, project and senior management level

- 4:15 *Mitigating client disruptions*

Buffer consumption data is used to gain cooperation from client in avoiding disruption

- 4:16 *Contracted sub-projects*

Subcontractors are aware of the ongoing project priorities.

- 3:4 *Load control*

The staggering process is closely followed to ensure reliable delivery

- 3:5 *Capacity elevation*

- 4:5.1 *Process of Ongoing Improvement*

Record, analyse and improve reasons for delay

- 4:5.2 *Expanding Capacity*

Ensure a capacity buffer is maintained

At each level of the S&T tree the format is the same with the assumptions linking the strategy with tactics (see Figure 3).

| 4:14 | Executing |
|------------------------|--|
| Necessary assumptions | <ul style="list-style-type: none"> ➤ Hectic priorities result in a “crisis mode” of management. ➤ The common practice of “turning task estimates into commitments” makes it uneasy for managers to intervene into a task execution early on. The combination of the above two phenomena delays needed management assistance. |
| Strategy | Projects are actively managed to ensure their successful, rapid completion. |
| Parallel assumptions | <ul style="list-style-type: none"> ➤ The only way to determine the priority of a task is by examining its impact on the completion of the project. In other words, priorities should be set ONLY according to the degree the task is consuming from its project (or feeding) buffer. Critical Chain Buffer Management is a priority system that operates according to this concept. ➤ Management assistance can usually help a top priority task. Helping top priority tasks is helping the projects. ➤ The assistance that can (and should) be provided by task manager is different in nature from the assistance that can be provided by project manager. Top managers assistance is sometime indispensable. |
| Tactics | 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. |
| Sufficiency assumption | Knowing when not to intervene is almost as important as knowing when to intervene. |



Figure 3 Example of the format and detail underpinning each level of the S&T tree

These assumptions (necessary, parallel and sufficient) are designed to support the logical links. The value in clarifying these assumptions is particularly evident in 5:131 Building the CC network diagram (PERT).

Very large projects are managed effectively by relatively small PERTs[network diagrams]; the PERTs used to build a north sea oil-rig (\$4B) and the overhaul of the largest cargo airplane (the C5) each have less than 300 tasks.

The following guidelines can help to tame the tendency to over-inflate a PERT:

- *A PERT is not a task manual.*
- *A PERT is not a reminder list.*

- *A task that takes less than 2% of the project's lead-time must have a very good reason to appear in the PERT.*
- *A task represents a group of work. It should not be broken down to several tasks just because it requires different resources for different durations of time. But it should be broken for chosen key-resource-types; a task should be defined so that those type of resources are required for most of the task time.*
- *In most multi-project environments many projects are variations of the same generic project. Using templates (PERTs of generic projects) as the base for constructing the PERT of actual projects, reduces drastically the required time and efforts and eliminates overly detailed tasks that should not appear in the plan.*
(Goldratt, 2007)

The S&T guide to CCPM implementation, therefore, provides an implementation methodology that can act as a basis for evaluating the CCPM approach. This provides a means of providing scientific rigor regarding an assessment of the explicit assumption and the recommended implementation process. However, any sizable implementation will require software support that also should be consistent with the implementation methodology. The choice of Concerto software is an appropriate choice, not only due to the close alignment with the S&T tree guide but its widely reported track record in the field.

CCPM Implementation Evidence

Case and survey research into the application of CCPM is still very limited. However, one measure of the level of interest in CCPM is the availability of CCPM capable project management software. There is a growing range of software systems claiming to be CCPM capable ranging in price from \$250. These includes: Concerto, ProChain, Spherical Angle,

Being Management, Scitor and Advanced Projects Inc. However, although this provides an indication of the level of commercial interest it is of little value in scientific evaluation without access to the software, the methodology of the implementation process and the system users.

Concerto supplied by Realization is a leading CCPM provider that has published customers' case studies including ABB, Delta, Boeing, US Marine Core Base, Lucent Technologies, Hewlett Packard and US Air Force Warner Robins Air Logistics Centre (Concerto Case Studies, 2009). Realisation has also been closely involved in the development of Goldratt's (2007) S&T implementation guide and the software is closely aligned with it. Using the Realisation Website (Concerto case studies, 2009) data, typical benefits include: reduced lead time by 25%; delivery performance increased to 90+%; and increased throughput by 20% with the same resource. Of these few have been formally published with one prominent exception, Warner Robins Air Logistics Centre (Srinivasan et al., 2007), where they implemented CCPM to reduce repair turnaround time on C-5 Galaxy transport aircraft.

Srinivasan et al., (2007) record that within 8 months of implementing CCPM using Concerto in 2005 the turnaround time was reduced from 240 to 160 days. What is more significant is that this was in addition to the benefits of lean initiatives started in 2000 that reduced the turnaround time from 360 to 240 days. The paper highlights the synergistic relationship between CCPM and lean with Concerto being used to identify several high-leverage lean events.

'For example, Concerto identified floorboard replacement as a chronic problem area that consistently consumed the project buffer. A resulting lean event reduced floorboard replacement time by about 45%.'

(Srinivasan et al., 2007, 18)

A recent notable application of CCPM in the construction sector is through the Japanese government public works programme. Due to the direct relevance of this work to the case research reported here the author visited Tokyo in August 2008 to collect research evidence directly.

Win-Win-Win Public Work Initiative, Japan

In Japan CCPM has only recently been available, but has rapidly become known for its impact on government construction projects where the use of CCPM has become a prominent part of the win-win-win public works initiative that is planned to be introduced nationally in 2009. The account given here resulted from personal interviews with Mr Yuji Kishira (Director of Japan TOC advancement committee) and Mr Kiyoshi Okudaira (Director General Ministry of Land Infrastructure and Transport) at the Ministry Building in Tokyo in August 08, together with published and unpublished documents. This account is presented here as it directly relates to the construction project management field of research in the water industry and offers evidence of much wider supply chain benefits associated with the application of CCPM.

Tight timescales on repairing earthquake damage before the typhoon season resulted in CCPM being used by a Japanese construction company Sunagogumi on a river bank reinforcement project for flood protection on the Tonebetsu river (Kishira & Ohara, 2005).

The approach was readily accepted by the foremen and the project originally scheduled for October 17 2005 was completed by mid-August. This provided clear benefits for the company, government and community as the early finish avoided exposure to the typhoon season. The company found that the CCPM approach also enabled them to inform the local community and local government of progress, so maintaining good relations and ensuring the

interim payments kept up with the early completions. The approach appealed to the local government official and the project received a very high evaluation for management and ingenuity, as well as shortening the schedule by 30% with a significant improvement in profits.

The importance of communicating with the local community resulted in them setting up a home page called 'site information centre' to provide information on objectives and progress. The benefit of clearly communicating the project status through buffer management and regular reporting was acknowledged as key to gaining what was referred to as 'Just-In-Time (JIT) information' across the project.

With this new capability Sunagogumi was able to win projects in tighter timescales and complete more projects with the same resource. This improved communication with the government departments and resulted in a collaborative development involving five pilot projects in the Kochi district. In parallel with this a government initiative to improve government response to the contractors was being trialled called 'One Day Response'. This One Day Response initiative proved to be particularly effective in combination with the application of CCPM resulting in an average reduction in duration of 20% compared to 28% delay on non-CCPM projects with an average increase in profits of 7%. The government supervisor highlighted it was easier to work with contract reports that did not include "saba" (a Japanese word for safety in each task). The government supervisor considered the method used by Sunagogumi without 'saba' made it easier for him to understand what was happening and, therefore, act more proactively than with the traditional methods used by other contractors - consequently, issues were resolved much sooner.

Following further trials and a survey of all parties this initiative has resulted in the broad adoption of what is referred to as Human Centred Project Management and a commitment by government officials to respond within 24 hours when their delay is resulting in project buffer

consumption. The initiative was launched at a conference in May 8 2007 with the launch of the Win-Win-Win Public Work Reform May 8 2007.

'We strongly remind ourselves of the very important responsibility of public works to secure people's safety and national land safety. To bring out maximum benefit for society, both government officials and contractors work together on public works by providing better products with faster speed. This brings benefits to all of residence, government and contractors and support to overcome financial difficulty of Japan Government. We declare herewith we strongly advance Win-Win-Win Public Work Reform.'

When I conducted my interviews in August 08 the Director General had gained agreement to expand the initiative across all Departments in Japan and a public works advancement conference was held in November 08 to promote the one day response initiative planned to commence in the next financial year.

Although the government could not promote CCPM directly it is clear from my interview and these conferences that CCPM is an integral part of this new initiative. However, due to limited direct observation there are still questions over the relationship between different aspects of CCPM and the Japanese Government initiative.

Conclusion

The above account has presented the logic, issues and case evidence associated with CCPM theory and practice. There is considerable evidence of practical benefit which is supported by conceptual argument, but there is little evidence of a rigorous nature.

More rigorous research is timely and has been assisted by the publication of a detailed implementation process guide in the form of the S&T tree (Goldratt, 2007) and the availability of software that is designed in line with this process as in the case of Concerto.

RESEARCH

Research method

The research was designed around the opportunity to invite water industry construction companies to participate in the live webinar delivered by Dr Goldratt over five 2 hour sessions from February to April 08. The basis of the webinar was the S&T guide to implementing CCPM.

The underlying research questions are:

- How and why does CCPM contribute to improved project management in practice?
- To what extent is the CCPM S&T implementation guide effective at guiding the CCPM implementation process?
- How does CCPM practice relate to wider operations theory?

One construction company participated in the webinar together with representatives from their supply chain, including the water supply company. In total 12 people attended and on completion of the webinar a Concerto approved CCPM consultancy was engaged to undertake a pilot implementation involving a number of projects. This involved Web access to the Concerto software and the implementation of the S&T tree guide, commencing with 4:13 (see Figure 2). During this period, from September 08 to the time of writing (February 09), three pilot projects were launched with two effectively completed. During this process the wider

supply chain was involved, including manufacturing suppliers, subcontractors and an external design team, together with active involvement by the water supply company.

The researcher was present during the webcast training, evaluation of CCPM software and throughout the pilot project. Progress review meetings involving the case company, consultant, the water company and suppliers provided regular updates, along with remote access to the Concerto software. Up to the time of writing, February 09, the S&T guide (Goldratt, 07) was being used by the consultant as the primary implementation guide with regular reference being made to it as the project progressed. In January 09 the pilot evaluation was progressing from the planning of single projects to developing a virtual drum as a basis for staggering a series of projects.

Research findings (interim)

The findings are presented using the S&T structure, commencing with the planning step. Due to the pilot implementation steps 4.11 (reducing bad multi-tasking) and 4.12 (full kit) were omitted.

Planning (4:13)

Network planning of projects was conducted centrally by the Planner and already operated within the guidance on activity task size (5:13.1). However, some tasks needed to be changed so they were not created around single resources. For example, in the case of 'laying a foundation slab' this activity was previously divided into multiple activities to reflect the different resources required. This economic based subdivision suits financial rather than flow requirements as there is a need to coordinate such activities as a whole – an issue very apparent in lean construction practice where local short term planning is encouraged with relatively large activities.

As recommended in the guide two days were devoted by the team and consultant to building a template network that ensured the plan was comprehensive and dependency links were valid. This resulted in a template network being created which was subsequently used with appropriate modification on the three projects.

Resource contentions were identified in determining the critical chain and the activity times were halved as specified in the guidance, putting 50% of the remainder in the buffer. During the webinar training some concern was raised over the potential to cut the activity time in half, but with the first project having been completed with buffer to spare this subsequently proved not to be an issue. The project buffer was smaller anyway due to 50% of the CC lead time comprising the external supply of a purification tank with a fixed delivery date, therefore, contributing no buffer. The staggering requirements (5:13:3) were in the process of being assessed in Jan 09, in line with the multiple projects that were to be subsequently planned. At the meeting much discussion ensued regarding the concept of a virtual buffer and the need to smooth the load rather than attempting detailed load control around a limiting resource, however, the outcome of this development has yet to be determined.

Executing (4:14)

During the Webinar the case for '*not turning a task estimation into a commitment*' was readily accepted together with the need to set priorities based on buffer consumption. The complexity of two buffer types (feeding and project) were not seen as over complex as suggested by Lechler et al. (2005).

The need to report regularly (daily) raised some discussion in the webinar as they would normally only formally report monthly using their company wide information system – a task undertaken by the Planner. However, it was acknowledged that more regular reporting was highly desirable and the reporting requirements of CCPM were simple in principle. The need

to simply report time remaining to completion was also accepted readily. In practice by January 09 they were reporting 2-3 times per week and it was acknowledged by all to take only a few minutes. The main difficulty raised was the incompatibility of the two systems and the fact that the Planner still had to construct a network plan and report monthly (including cost data) on the central information system. However, as activity progress updating had been devolved to the task managers through the Web access capability of Concerto his work had also reduced. The task managers appreciated the enhanced visibility offered by the system including the relative priority of activities that were their responsibility. This included activities in progress and those on their way with projected availability. This meant that the task managers were in a position to prepare in advance for tasks coming their way.

As well as the task manager having visibility the project manager was monitoring regularly, if not daily, ensuring timely updates by the task manager were being made and enquiring after tasks that were consuming buffer. In practice this was acknowledged to encourage a culture of regular updating by the task managers. They also acknowledged that where recovery action was needed, which happened on several occasions, it was addressed in a much more timely fashion than previously. The system also provided a means of recording what action had been taken on such occasions and in support of the continuous improvement process a 'reasons for delay' list was developed in line with the S&T guide.

Project and top manager visibility of the projects was much improved, together with the ability to ask pertinent questions over the reporting procedures of subordinates. As Elton and Roe (1998) argued CCPM provides a means of establishing disciplined and consistent procedures and priorities. To provide visibility of numerous projects a fever chart is used to convey the progress of projects in relation to the completion of the critical chain and the

consumption of the project buffer, which was acknowledged to provide improved project control data in both clarity and timeliness.

Mitigating Client Disruption (4:15)

The involvement of water company representatives with Web access to the software has enabled the wider supply chain issues to be recognised and enabled the next stage in the pilot trial, where agreement will be necessary to enable effective staggering of projects. The potential of enhanced cooperation is acknowledged and being explored with both the scheduling of work, based on flow (as opposed to economic financial objectives) and resolving causes of delay, as illustrated through the Japanese government initiative detailed earlier. However, this potential development goes beyond the guidance offered in the S&T Tree which suggests a direction for extending the S&T tree.

Contracted Sub-Projects (4:16)

Involvement of suppliers and subcontractors from the beginning has enabled them to be involved in the updating of the project and associated tasks. There are clear benefits for them and, therefore, there is little difficulty in gaining their involvement, but this has only been made possible through the Web access capability of Concerto. In the case of the purification tank supplier, they regularly update progress in relation to their promised delivery dates to the projects, thus avoiding project update requests. This also gives them visibility of actual as opposed to planned requirements for the tank and therefore the potential for them to accommodate changing priorities. This wider participation also goes beyond the modest expectations and guidance of the S&T tree.

Continuous improvement (4.51)

The need to continually improve the process by analysing causes of delay is readily accepted by the senior management and data is now being collected, but no formal analysis had taken place at the time of writing. This capability is relatively new to the Concerto software, bring it inline with Goldratt's S&T tree, and we have yet to determine how effectively it is in this study.

Conclusion

This relatively brief account illustrates the general benefit of the S&T guidance and the CCPM approach to this company and supply chain. A more detailed review is in progress and will be extended to encompass multiple project staggering and hopefully full implementation. The case has, however, enabled some of the previously claimed weaknesses to be tested.

DISCUSSION

Having taken account of the critical literature, the industrial successes and this interim study there is little doubt that there is clear merit in the approach that is both practical and theoretically supported. The S&T guidance to implementation adds further rigour and a basis for testing and developing best practice. However, there remain questions over elements of the approach and the underlying assumptions. These include buffer sizing, the practice of setting and adjusting virtual drums and focusing continuous improvement. Academics will naturally focus on these bite sized elements but there is also a need to view this work more broadly in the context of other developments in operations management theory.

Flow versus cost focus

CCPM, as with lean thinking before it, emphasises enabling flow and continuous improvement rather than the sub-optimisation associated with economic models. Theory in

manufacturing made a break from cost models in the West with the realisation that different levels of variation and uncertainty in the market and delivery system result in the strategic choices that needed to be aligned with the market (Skinner, 1969, 1974; Hayes and Wheelwright, 1979; Hill, 1985). The need to make such choices was closely associated with the concept of trade-offs which was subsequently challenged by the TPS focus on flow and reducing wasteful variation and uncertainty. The cumulative capability model (Ferdows and De Meyer, 1990) emerged and subsequently led to theoretical models that encompass flow, trade-offs and continuous improvement (Schmenner and Swink, 1998; Fisher, 1997; Stratton, 2008). However, it is clear that academic theory lags practice in the field by decades in some cases.

Project management is a distinct field within operations management but the same underlying principles of flow and continuous improvement would appear to apply, all that differs is the means of applying these principles. The same lessons are now being applied to project management through lean construction and CCPM but there is a need for academia to more constructively contribute to the process by more actively working with industry to lead such theoretical developments and practically test and support the development of effective practice.

CONCLUSION

This paper set out to review CCPM in the light of existing literature, industrial practice and case research. The case research utilised Goldratt's S&T guidance which embodies 10 years of development and has attempted to test the procedure and logic embedded within this guide. The evidence, so far, indicates the guide is both comprehensive and supportive of the implementation process and clearly has improved on earlier guidance in terms of depth, breadth and several areas of improvement. The research findings identified that many of the

areas of weakness cited in the literature were not warranted or not significant to this case study. Areas for further research have been identified together with the potential to more tightly define and extend the guidance.

The overall consensus of the pilot evaluation is very positive and provides a significant improvement on prior practice with the main obstacle being the need to duplicate planning on the two systems. The paradigm shift in thinking associated with this implementation of CCPM has been readily accommodated and the opportunities are now being considered in relation to the entire supply chain with the Japanese case clearly highlighting the possibility of wider benefits.

From a theoretical perspective CCPM would appear to be aligned with existing theory in operations management as it follows the principles of flow and continuous improvement that can be traced back to Ford (1926) and Shewhart (1939). There is, however, a need to bring together the parallel but often separate lean and TOC centred research in developing the application and the underlying theory of project management.

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