

WHY CRITICAL PATH SCHEDULING IS WILDLY OPTIMISTIC! (or why so many projects finish late)

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Introduction

The ‘critical path’ scheduling methodology developed in an environment of certainty. This paper will suggest that when dealing with major projects in the modern age, the projected end date calculated by CPM tends to be widely optimistic. However, through the prisms of complexity theory, in particular CRPR, and motivational theory this is not necessarily a bad thing.

The factors that drive CPM towards an optimistic initial assessment include psychological biases, single point estimates and limitations of the CPM modelling process (including a factor previously identified as PERT Merge Bias). As work progresses, these initial biases are compounded by the inability of CPM to adjust future predictions based on performance to date. Some of the solutions developed from EV theory such as ‘Earned Schedule’ provide a partial answer but are also limited.

From the perspective of CRPR and motivation theory, having an optimistic schedule can be beneficial. Concepts such as Critical Chain are based on the value of an optimistic schedule as a motivator and behavioural change agent. Therefore, if used as a motivational communication tool, the ‘optimistic schedule’ has many advantages.

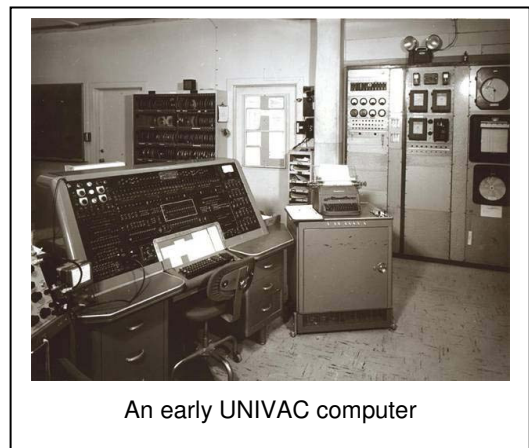
The challenge is fitting an optimistic scheduling process within the constraints of an organisational governance structure that requires an accurate prediction of the likely completion date and traditional contracts that demand a ‘contract schedule’ and include significant sanctions if the CPM schedule predictions prove incorrect.

The paper will review a number of emerging methodologies including Critical Chain, Momentology, RD-CPM® and Schedule Density. It will conclude by suggesting a range of practical measures based on embracing uncertainty and using predictive tools that in combination can provide the degree of insight, motivation and control needed to blend the desirability of an optimistic schedule as a workforce motivator with management’s need for a predictable and reliable project completion date.

The Basis of CPM

Origins of CPM

The origin of CPM can be traced to mid 1956. E.I. du Pont de Numours (Du Pont) was looking for useful things to do with its ‘UNIVAC1’ computer and Du Pont’s management felt that ‘planning, estimating and scheduling’ seemed like a good idea! Morgan Walker was given the job of discovering if a computer could be programmed to help and in the period from late 1956 through to April 1957, Walker assisted by Kelly and others had scoped a viable project. Their challenge was to solve the time-cost conundrum. They could demonstrate that in preference to flooding a project with labour to recover lost time, focusing effort on the ‘right’ tasks can reduce time without significantly increasing cost. The problem was identifying the ‘right’ tasks! (Weaver, 2006)¹



An early UNIVAC computer

¹ See: ***A Brief History of Scheduling - Back to the Future:***
http://www.mosaicprojects.com.au/Resources_Papers_042.html

Around the same time, the USA Navy started two separate projects, the PERT program and a review of dockyard management processes by Dr. John Fondahl that resulted in the PDM networking methodology (Weaver, 2007)

Limitations of the CPM modelling process

The design of the CPM and PERT systems was severely constrained by the limitations of the available computers. Simple modelling processes were essential. The PDM methodology developed by Dr. Fondahl was developed as a manual system to bypass both the cost and processing limitations imposed by the then available mainframe computers. Whilst PDM was quickly computerised, and manual version of CPM and PERT were developed, simplicity remained essential. These early constraints no longer exist, modern computers have an excess of processing capability, but the CPM methodology has largely failed to take advantage of the enhancements in technology. Two of the major issues are defined below.

Single point estimates

CPM by definition uses a single point estimate. Whilst this produces an illusion of accuracy, the summation of the single point estimates provide a single predicted completion date, the basis of the calculation is uncertain (Mosaic White Papers #1). Estimating the duration of any activity can at best be founded on recent experience of completing a similar task, but the past is no guarantor of the future.

Limited logical statements

The limitations of the logical statements possible in standard CPM also create significant limitations. Very rarely is there a real constraint that precisely defines the relationship between two activities. Finish-to-Start mandates 100% completion before any work can start on the successor, reality suggests there's usually a few minor elements of work that either be started before, or finished after the bulk of the work has transferred from the preceding task to the succeeding task. As soon as overlaps are introduced significant additional problems are introduced both from the perspective of understanding the intended flow of work and potential calculation anomalies (Mosaic Core Scheduling Paper #4). Additionally, CPM has no concept of variable logic in the form of loops and conditional branches to deal with issues such as re-work and re-testing due to a test failure.

The CPM Model Summary

The CPM modelling process does not replicate real life; it is a simplified model of the project that can be very useful provided its limitations are understood.

CPM Estimating Biases

Psychological biases

Developing a schedule requires two sets of interlinked decisions; the first is defining the activities to be scheduled and their logical interdependencies. The second involves determining the duration of each activity. These decisions are the subject of personal preferences and biases.

The definition of each activity is subjective; people decide how to segment the work into activities and if it is better to group several trades together (eg, form, reinforce and concrete a slab) or to separate the

trades into different activities for formwork, reinforcement and concreting. There is no ‘right’ or ‘wrong’ in these decisions, the optimum choice is based on industry norms and established practice overlaid by defined ‘good practice’ (Mosaic Core Scheduling Paper #1) and the personal preferences of the project team. Based on the decisions pertaining to activity definition, the subsequent development of the preferred flow of work as defined by the schedule logic is clearly based on personal preferences. Whilst there is some mandatory logic in every schedule, most decisions are subjective based on the teams assessment of good practice. Furthermore, the decisions are overt and the resulting logic diagram can be critiqued, debated and agreed.

Less apparent, is the psychological biases that affect duration estimates. There are many different biases that affect all of us, most tend towards optimism. Some of the key influences are:

Optimism bias

Optimism bias is the demonstrated systematic tendency for people to be overly optimistic about the outcome of planned actions, including over-estimating the likelihood of positive events and under-estimating the likelihood of negative events (Wikipedia #1).

Expectation bias

Expectation bias (or experimenter’s bias) is the tendency for experimenters to believe and publish data that agree with their expectations for the outcome of an experiment, and to disbelieve, discard, or downgrade the corresponding weightings for data that appear to conflict with those expectations. Most project schedules are built against a pre-determined end date. This bias pushes people towards believing durations that achieve the target and rejecting durations that would cause overruns (Wikipedia #2).

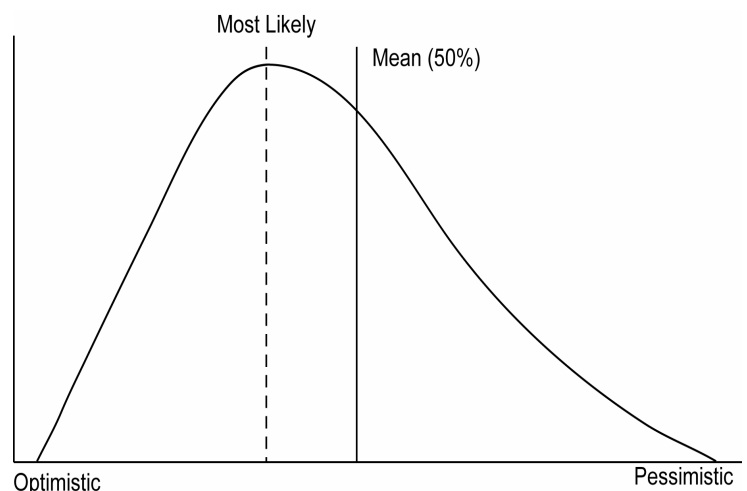
Confirmation bias

The tendency for people to favour information that confirms their preconceptions or hypotheses regardless of whether the information is true. As a result, people gather evidence and recall information from memory selectively, and interpret it in a way that supports their original predisposition. This bias tends to support the validity of the original optimistic estimate! (Wikipedia #3).

CPM Modelling biases

Variability distribution (the PERT effect)

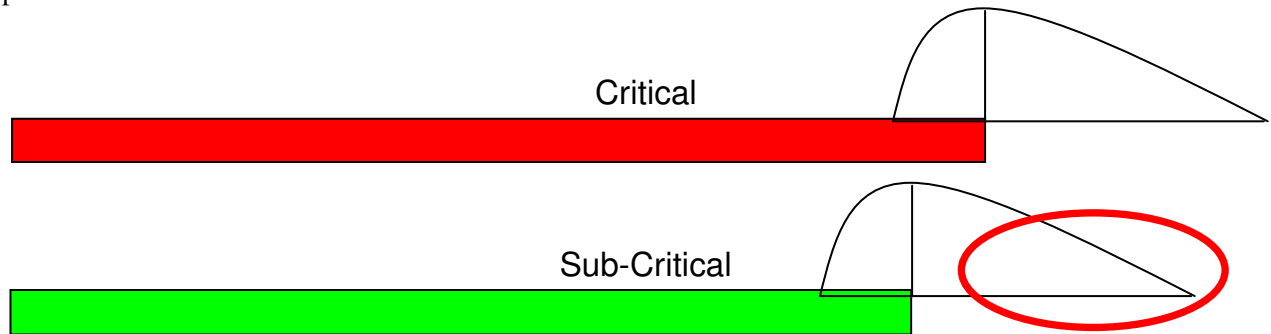
Most duration estimates are based on a ‘most likely’ duration. Because CPM only allows one estimate, this most likely duration is itself optimistic. With most project activities, the numbers of things that may go wrong significantly outweigh the number of things that may go better than estimated producing a skewed probability distribution (Weaver, 2008)².



² See: *The Meaning of Risk in an Uncertain World:*
http://www.mosaicprojects.com.au/Resources_Papers_040.html

Merge Bias

CPM calculates the critical path and float on non-critical paths but makes no allowance for the impact of variability on the likely completion of any path. This phenomena has been defined in the past as 'PERT Merge Bias'; and whilst not calculated in CPM, the risk of delayed completion is significantly increased if there are multiple critical paths, and more importantly if there are multiple sub-critical paths with minimal float.



As float is reduced on sub-critical paths, the probability of completing the overall project on time reduces because the likelihood of the sub-critical path becoming the key delay to completion increases.

CPM Predictive Biases

Performance Factors

The underlying assumption in CPM is that incomplete work will be accomplished according to the original plan. Good practice requires all incomplete work to be moved forward of time now to recalculate the expected completion date for the project. However, beyond this simple expedient most contracts actively discourage the reassessment of durations based on current experience/performance (Weaver, 2010). This creates a major optimistic bias, firstly by not adjusting the 'risk of delay' based on the consumption of float on sub-critical paths (as discussed above) and secondly by failing to recognise the effect of actual performance to date

No scaling of remaining durations

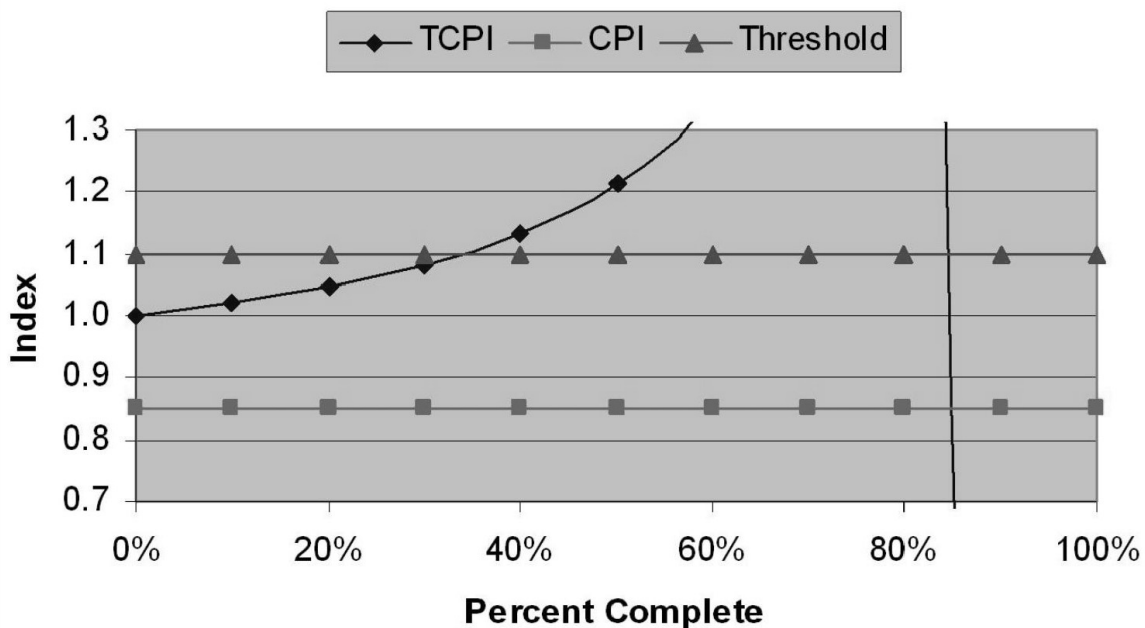
The lack of any 'scaling' function in standard CPM causes all future work to be scheduled based on the original estimated durations, which themselves are likely to be optimistic. If the performance to date has consistently shown the duration estimates to be 10% optimistic, the most likely future outcome will be a 10% overrun on all remaining durations. Even if actions are instigated to improve performance they will take time to have an effect. The Earned Value community have long recognised the best indicator of future cost performance is current performance. I would suggest the same applies to schedule performance. Failing to take this factor into account increases the optimistic bias in progress reports. The Earned Schedule addition to standard EV uses the overall productive efficiency achieved to date to calculate a likely completion date.

The mathematics of 'losing' - The TCPI effect

The concept of the To Complete Performance Index (TCPI) measures the increase in performance needed to recover lost time (or cost).

If a project is 50% complete and overall the work has achieved 80% of the required production (an SPI of 0.8), the increase in performance needed to not lose any more time is 20% (an additional SPI of 0.2: $0.8 + 0.2 = 1.0$).

To recover the lost time before the end of the project, an additional performance factor of 20% would be required to offset the 20% lost to date. The required SPI for the remaining work becomes $0.8 + 0.2 + 0.2 = 1.2$. This is an increase of 0.4 on a base production rate of 0.8 or a 50% increase in productivity. Assuming the work is based on a 5 day week, the required level of production is now 7.5 days per week! (Weaver, 2001)³.



The benefits of an optimistic schedule

The schedule as a motivator

If the schedule is expected to be an accurate predictor of the future, the optimistic biases outlined above are detrimental. However, if the schedule is seen as a proactive aid to the effective management of the use of time, setting optimistic targets to motivate team performance can be highly beneficial. What is needed is a paradigm shift in the way the schedule is perceived, constructed and used.

Complexity Theory and CRPR

Complexity theory is a relatively new branch of science that is increasingly being viewed as important in understanding the dynamics of projects (Weaver, 2007B). Complexity theorists are interested in the

³ See: *The Project Start-Up Conundrum*: http://www.mosaicprojects.com.au/Resources_Papers_003.html

underlying rules that govern apparently chaotic behaviours. Chaordic systems exhibit a degree of predictability at their higher levels but are completely unpredictable at the detail level. Examples include the weather and projects.

Within complexity theory, the Complex Responsive Processes of Relating (CRPR) sees the delivery of the project being crafted by thousands of individual decisions and actions taken by people who are 'actors' within the social network of the project team and its immediate surrounds. The role of 'project management' is to motivate, coordinate and lead the team towards the common objective of a successful project outcome. In this environment the project schedule has two key roles to play, firstly as a tool to develop a common understanding of the optimum approach for achieving the project objectives and then as a flexible tool to measure the inevitable deviations from the plan and re-assess the best way forward (Weaver, 2009)⁴. When designed properly, the schedule provides the framework to support effective decision making by all members of the project team.

Motivation theory

One aspect of motivation is providing people with a challenge they can understand, and a reward when the challenge is achieved. The schedule can provide a very effective motivator, setting targets people can strive to achieve. Making the schedule an effective motivation tool requires involvement and the transfer of a degree of 'ownership' to the project team (Mosaic White Papers #2)⁵. When this is achieved, the schedule has proven to be a very effective motivator.

Proven effective

Critical Chain

Critical Chain sets 'stretch targets' for every task duration. The reported effect is a major improvement in task delivery times (Mosaic White Papers #3)⁶.

The VIPER experience

VIPER is an on-going Australian Air Force maintenance program. The time required to complete the deep level maintenance of an aircraft improved significantly for similar reasons to Critical Chain (Weaver 2003)⁷, the scheduling system inadvertently reduced task durations on a progressive basis over several years and the workforce adapted to the new targets. The resulting improvements in the time needed to return aircraft to service was awarded by a Prime Ministers Citation.

⁴ See: *Scheduling in the Age of Complexity*:
http://www.mosaicprojects.com.au/Resources_Papers_089.html

⁵ See *WP1048, Motivation*: http://www.mosaicprojects.com.au/WhitePapers/WP1048_Motivation.pdf

⁶ See *WP1050, Critical Chain*:
http://www.mosaicprojects.com.au/WhitePapers/WP1050_Critical_Chain.pdf

⁷ See: *The VIPER Experience*: http://www.mosaicprojects.com.au/Resources_Papers_012.html

Determining a realistic completion date

Managing Risk

Setting an optimistic schedule requires pragmatic risk management. Critical Chain uses the concept of 'buffers' CPM needs a similar approach to develop appropriate reserves⁸.

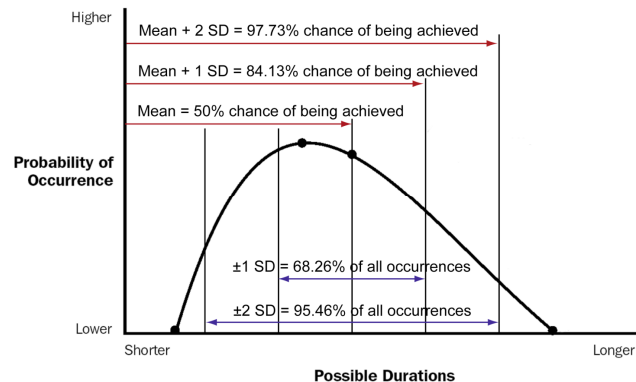
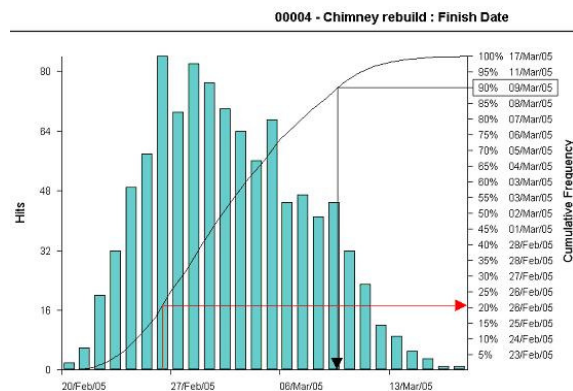
Contingency & Management Reserves

In addition to pragmatic allowances for identified risks such as inclement weather and test failures, an optimistic CPM schedule needs a realistic buffer to allow for some of the work taking longer than allowed. Determining an appropriate allowance requires historical data. Decisions on where to hold this allowance, either within the overall project or outside of the project depends on management's approach to the overall management of risk.

Managing variability in duration estimates

Monte Carlo

All durations are uncertain estimates of what may happen in the future. Using Monte Carlo allows a realistic allowance for the variability to be calculated and the appropriate buffer assigned to the project. This analysis can be a valuable input to the calculation of an appropriate reserve, allowing a stretch target to be set with the buffer creating an acceptable level of risk. Management's risk appetite will determine the size of the buffer needed.



Managing variability in actual performance, Earned Schedule

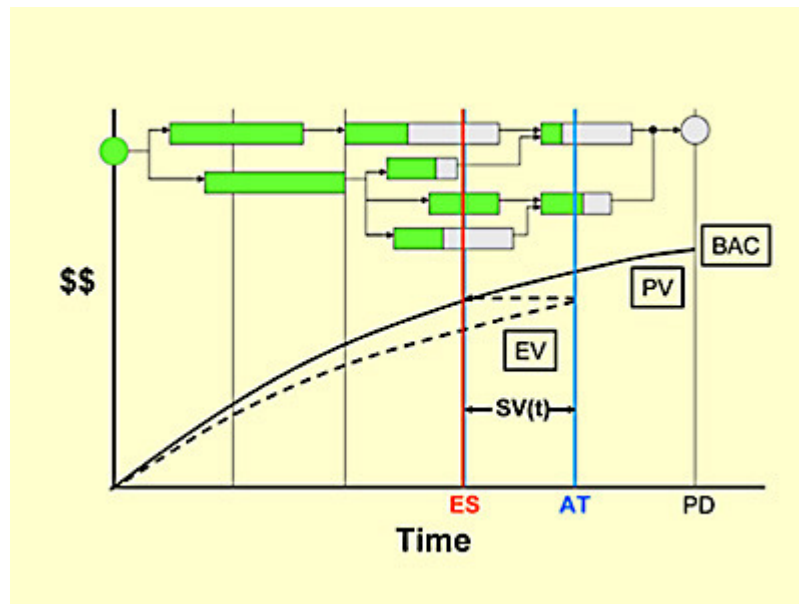
CPM has no effective way of scaling future performance based on the actual performance to date. Earned Schedule has evolved to the point where given the necessary data; a reliable prediction of the end date is possible (Lipke, 2009).

The 'P' Factor

One of the key elements within Earned Schedule is the recognition of the 'P Factor'. The P-Factor measures how well the project is following its planned schedule i.e., its *schedule adherence*. Adhering to the planned sequence of tasks ensures that the predecessors to the tasks in work are complete,

⁸ See: *The Meaning of Risk in an Uncertain World*.
http://www.mosaicprojects.com.au/Resources_Papers_040.html

minimising the potential for rework. Non-adherence is frequently an early warning indicator of other problems.



Earned Schedule

Trend analysis and TCPI(t)

The data developed from an effective Earned Value system, expanded to include Earned Schedule provides projected end dates and the previously discussed TCPI for time $TCPI^{(t)}$ indicates the change in performance needed to achieve the target completion with the same degree of accuracy traditional EV provides for cost performance. However, whilst the projected completion is useful, other options are needed to change performance.

Emerging ideas

Momentology, measuring the effective momentum of work

M. Woolf has described the concept of Momentology in his book, *Faster Construction Projects with CPM Scheduling* (Woolf, 2007). Momentology focuses on establishing and maintaining the momentum of work across the whole project (Mosaic White Papers #4)⁹. Loss of momentum is another good early warning indicator of emerging problems.

RD-CPM®, Relationship Driven variant of CPM

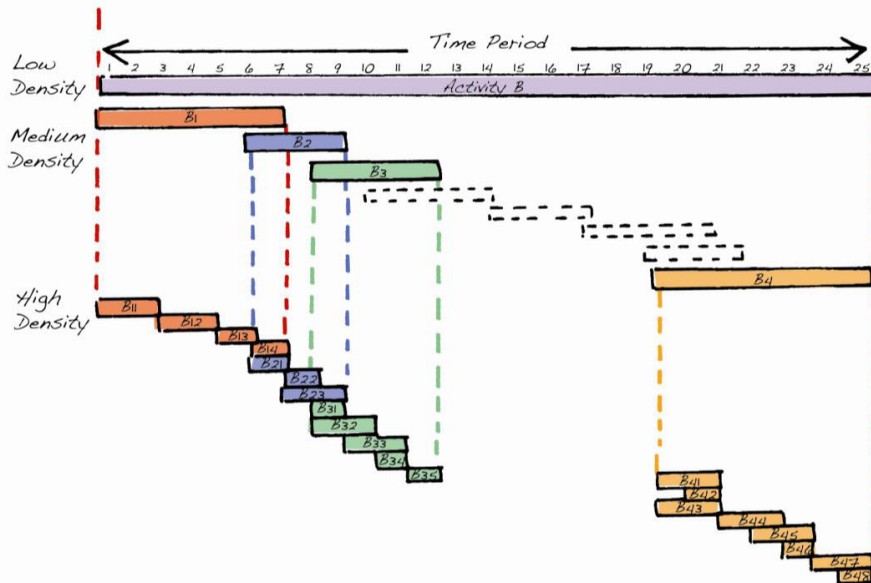
The relationship driven variant of CPM focuses on a different weakness in standard CPM, defining and managing the ‘gaps’ between the tasks. RD-CPM has improved the number and type of links and there effect on schedule calculations allow a more sophisticated schedule to be developed (Mosaic White Papers #5)¹⁰.

⁹ See **WP1036 Momentology**:
http://www.mosaicprojects.com.au/WhitePapers/WP1036_Momentology.pdf

¹⁰ See **WP1035 Relationship Driven CPM**:
http://www.mosaicprojects.com.au/WhitePapers/WP1035_RD-CPM.pdf

Schedule Density and the pro-active the management of time

The newest idea ‘Schedule Density’ takes a different approach and can be used with any of the foregoing ideas. The key concept in schedule density is that there is no point in developing a detailed schedule that is guaranteed to be wrong. You can’t create detailed schedules for work you do not have detailed knowledge of, including knowing who will be doing the work and how effective they are. Schedule Density sets an overall time budget at ‘Low Density’ and re-plans the work in greater detail as the density is increased. The re-planning takes into account the actual situation, actual production rates and the objectives set by the Low Density schedule to encourage the proactive and effective management of time (Mosaic White Papers #6)¹¹.



Schedule Density increases detail at the appropriate time

Practical thoughts for an overall approach to time management

Developing a ‘useful’ optimistic CPM Schedule

Schedule levels / Schedule Density

The overall schedule development needs to be focused on creating usable and understandable schedules that are not so large that management cannot understand the information. On a major project this will require the use of *schedule levels* linked to *schedule density* (Mosaic Core Scheduling Paper #6)¹².

Plan what’s known with the people responsible for the work

The planning process needs to engage the right people at the right time. Low Density schedules and setting the time budget engages senior managers. The Level 4, Medium Density schedule should be

¹¹ See WP1016 Schedule Density:
http://www.mosaicprojects.com.au/WhitePapers/WP1016_Schedule_Density.pdf

¹² Download from: http://www.mosaicprojects.com.au/PDF/Schedule_Levels.pdf

developed in conjunction with the management of the key suppliers and subcontractors working on the project. High density schedules should involve the people and team leaders actually doing the work.

Engage stakeholders: Last Planner

The 'Last Planner' concept is critical, the Level 5 'detailed look ahead' schedules need to have the input of the immediate team leaders who will be directing the day-to-day work of the project over the next week or two. These schedules need to be realistic, resource loaded, and take into account work space, access routes and current production rates.

Skilled schedulers

Managing this type of interactive scheduling requires skilled schedulers. Their personal attributes, including good communication skills and a relatively high EQ are discussed in Mosaic's 'Core Scheduling Paper #2: *The Roles and Attributes of a Scheduler* (Mosaic Core Scheduling Paper #2)¹³.

Changed approach to 'contract schedules'

The concept of a fully detailed contract schedule produced within a few weeks of a project starting is heavily enshrined in contracts and contract law. Research by the Chartered Institute of Building (CIOB) has suggested a more proactive approach to time management endorsed by this paper (CIOB, 2010). The traditional approach to contract schedules tends to focus on measuring failure. Effective time management focuses on making the best use of the available time within a contract to achieve the contracted objectives.

Manage the schedule

Updating for effect

The updating process can be a simple clerical exercise or a way of ensuring commitment and action on the part of the project team. The key element is changing the focus from the past (measuring % complete) to the future, asking 'How long do you need to finish?' Historical data is important, but making sure the project team are committed to future actions is more important (Weaver, 2002)¹⁴.

Proactive management of time

Time is not cost. You can save money and spend it later, time effluxes at the rate of 60 seconds per minute, every minute of the day. The past is unchangeable history, the present is too late to change and any successes or failures are in the hands of the project team. The role of proactive time management is to set up future activities for success. This is an on-going process involving regular checks to ensure short term objectives are being worked on in accordance with the schedule, regular updates to keep the schedule current and strategic reviews to increase density at the appropriate times and re-work the plan to achieve the project objectives as necessary.

Proactive management of delays and disruption

Delays are almost inevitable. The challenge facing project teams and their clients are the timely and effective management of the delay whilst maintaining as nearly as possible the original objectives of

¹³ Download from: http://www.mosaicprojects.com.au/PDF/Attributes_of_a_Scheduler.pdf

¹⁴ See, *Managing for Success - The power of regular updates*:
http://www.mosaicprojects.com.au/Resources_Papers_002.html

the project. The assessment of the delay needs accurate and timely information; effective updating should provide this. The assessment of the delay requires the use of appropriate protocols and techniques (Weaver, 2011)¹⁵, the *Delay & Disruption Protocol* developed by the Construction Law Society (CLS, 2002) provides useful guidance. However, the delay should not be used as an excuse for failing to achieve the project objectives. Effective time management should focus on achieving the best possible outcome!

Focus on success rather than measuring failure

In summary, the effective management of time requires a focus on success rather than the measurement of failure. This requires all parties to a contract or project to recognise predicting the future is impossible. Then by accepting the fact that every schedule will be wrong to a greater or lesser extent, procedures can be implemented to use the schedule as an effective communication medium focused on optimising future actions and motivating, and coordinating the work of the project team.

Conclusion

Traditional CPM has an approximately 20% optimistic bias.

The innate biases built into CPM and inherent in people will inevitably create an optimistic schedule. This is a valuable motivation factor and should be encouraged provided there are adequate allowances built into the risk management system to compensate for possible slippage. If the motivation works, the project will finish early. If some delay occurs and the project trends towards a more normal outcome, the contingencies should ensure a successful outcome. A useful heuristic is to assume a 10% to 20% optimistic bias.

Time management is a continuous process

Traditional approaches to contract programs simply measure failure against a highly detailed, static schedule. The approach suggested in this paper and the CIOB *Guide* is to proactively manage for success. This is continuous process that uses the schedule to align, coordinate and motivate the project team to achieve the overall project objectives. No one benefits when a project finishes late.

Predicting project completion

CPM is demonstrably optimistic in any projection of project completion. To define a realistic and achievable completion date, properly calculated contingencies and reserves need to be added to the net CPM schedule. Once work is in progress, predictive tools such as Earned Schedule provide more reliable end dates than CPM.

¹⁵ See: ***Assessing Delay and Disruption - Tribunals Beware.***
http://www.mosaicprojects.com.au/Resources_Papers_035.html

Combining the motivation of CPM with the prediction of ES provides overall control

The optimistic bias of CPM is both useful and effective as a project team motivator if properly used. Critical chain has demonstrated one way to achieve this VIPER a similar but different way. Pragmatic management needs to balance this optimistic striving for the best possible outcome with realistic contingencies and predictive systems that define a completion date that has a high probability of being achieved.

Where formal contracts are in place, the contracts need to be modified to encourage proactive partnering to achieve success. The framework defined in the CIOB *Guide* has been developed with this objective in mind.

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- Schedule Float: http://www.mosaicprojects.com.au/PDF/Schedule_Float.pdf
- Schedule Levels: http://www.mosaicprojects.com.au/PDF/Schedule_Levels.pdf
- Schedule Calculations: http://www.mosaicprojects.com.au/PDF/Schedule_Calculations.pdf

Additional information; see Mosaic's Scheduling Home page at: <http://www.mosaicprojects.com.au/Planning.html>