Scheduling Challenges in Agile & Distributed Projects[1]

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Introduction

Critical path theory is based on an assumption that to deliver a project successfully there is one best sequence of activities to be completed in a pre-defined way. Consequently, this arrangement of the work can be modelled in a logic network, and based on an analysis of the resulting schedule the project's critical path, overall duration, sub-critical paths and float can be calculated. Then, as work proceeds, and based on this schedule model, the effect of actual progress, and the consequences of any delays can be reliably calculated.

The Critical Path Method (CPM) of scheduling has been in relatively wide-spread use for more than 60 years and the theory of CPM scheduling has underpinned the way:

- Contracts are drafted, particularly in the defence, engineering and construction industries
- Legal precedents have been set, based on expert opinion derived from CPM analysis, and
- Project controls practices have evolved.

However, while CPM has proved to be an effective controls tool for many types of projects, it is equally apparent the CPM paradigm does not apply to a wide range of other project types including soft[2] projects and distributed projects. For this non-CPM class of project, there may be a high-level road map outlining the desired route to completion and/or specific constraints on the way parts of the work are sequenced, but a lot of flexibility remains in the way the rest of the work is accomplished.

The constraints on how the work of a project should be sequenced ranges from very few constraints in some soft and distributed projects (the work can be done in almost any sequence), through to highly constrained projects where there really is only one best way of doing the work.

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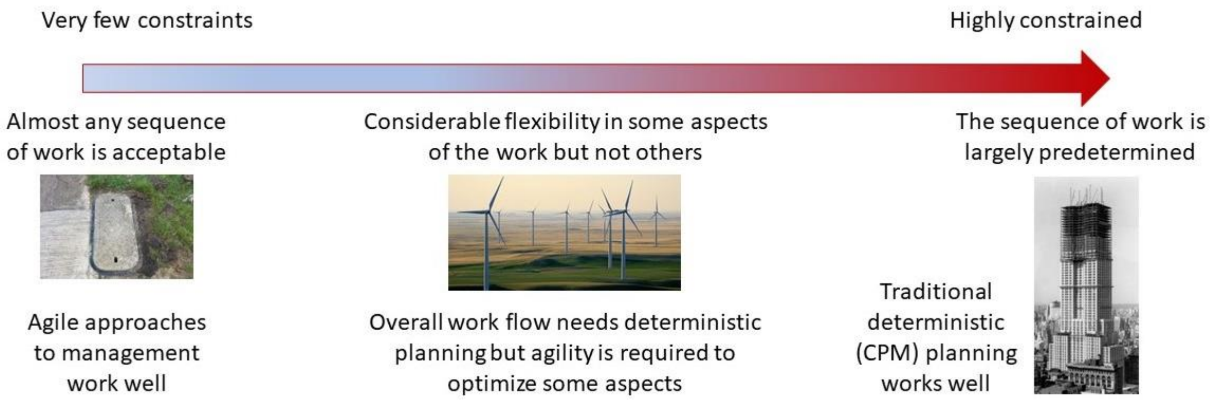
[2] Soft projects are defined as ones where the majority of the work has a degree of flexibility on how the required functionality is achieved. Soft and distributed projects are defined in more detail later in this paper.



The challenge facing many project controls professionals, and the organizations that employ them, is a misplaced assumption that CPM scheduling is the best approach for implementing schedule control on all types of projects. This paradigm is being increasingly challenged and in in many cases there is a deliberate management intent not to follow any predetermined sequence of activities, other approaches such as agile and lean are preferred. Arguably these methods can and do achieve better outcomes in the right situation, but their ability to provide management oversight and controls appears to be limited to a few visual charts.

The use of simple visual charts for an internal project may be acceptable. The lack of consistent and verifiable calculations in the agile and lean methodologies, that predict the current expected completion date, or assess the effect of imposed delays and/or scope variations, are not likely to be an issue. Everyone works for the same organization, in theory have the same strategic objectives, are interested in delivering value, and can be expected to engage in constructive discussions to resolve issues and reframe priorities. This is essentially the message in the Agile Manifesto, and achieving a culture that allows this approach to managing projects to flourish is a governance issue.

However, if the project is being performed under a more traditional fixed price, fixed scope, fixed duration contract, not having good controls information can be very detrimental to both the contractor and the project client. Proactive issues management and partnering to achieve mutual success is still desirable but ultimately the courts will determine contractual disputes based on applying the law to the terms of the contract.

The focus of this paper is to:

- Briefly define the management assumptions that support the use of CPM scheduling, its origins, and limitations
- Develop a classification framework of project characteristics to help define the potential usefulness of CPM scheduling
- Briefly describe some of the management approaches currently used in non-CPM projects including agile and lean, their benefits and limitations

- Consider the application of the framework discussed above applied to a typical wind farm project
- Develop general recommendations for the management of non-CPM projects focused on optimizing the efficient use of resources.

Based on this foundation, two additional papers will look at:

1. Implementing a robust system for reporting progress and predicting completion in agile and distributed projects that can be applied to any class of project.
2. Assessing delay and disruption in agile and distributed projects where the use of a CPM schedule is not viable.

Traditional CPM in Project Controls

CPM theory and calculations have been in relatively widespread use for more than 60 years. CPM was developed in 1957 and by the early 1960s CPM and PERT had merged into a general approach to network scheduling[3] primarily used for controlling defence, engineering and construction projects. The fact CPM has survived from that time through to the present, virtually unchanged, is because CPM schedules are useful in a lot of situations. Plus, I suggest, there is an entire industry devoted to maintaining the CPM status quo.

This section briefly looks at the origins of the management concepts that underpin CPM and the benefits and limitations of using CPM.

Scientific management

Most of the concepts used in modern project management, as it developed from the 1960s through to the 90s, were derived from the concepts of scientific management. Scientific management is a management theory that was developed in the early 20th century by people such as Frederick Taylor and Henry Gantt (mainly in the decade 1910 – 1920).

Scientific management assumes, amongst other things, that 'supervision must be achieved through a clear chain of command and through the application of impersonal rules' and that 'only those at the top have the capacity and opportunity to direct the enterprise'. This overall approach is supported by the assumptions there is 'one best way' to do a job and this best way can be discovered and improved by applying a reductionist approach to complex endeavours, supported by the division of labour. These scientific

[3] For more on the origins of CPM and PERT see ***A Brief History of Scheduling***: https://mosaicprojects.com.au/PDF_Papers/P042_History_of_Scheduling.pdf

management concepts are central to many modern project management processes such as developing the Work Breakdown Structure and developing a CPM schedule.

The critical path method (CPM)

The critical path method of creating a schedule follows the paradigm outlined above:

- The schedule is developed by a scheduler working for the project manager (or by the project manager)
- The development of the schedule is usually done before most of the suppliers, subcontractors and people who will actually do the work of the project are available for input
- The work of the project is reduced to a series of activities, the planner seeks to optimize the activity duration, resource requirements and cost
- The work sequence is defined by the arrangement of the activities in the schedule, determined by the links imposed between the activities
- Once approved, the schedule is assumed to represent the best way of accomplishing the work of the project. It is imposed on the project team, it defines how the work will be done, how progress will be measured, and is frequently incorporated as part of head contract requirements, subcontracts and purchase orders
- Suppliers, subcontractors and other people working on the project are expected to do their work as planned.

The outline above varies from project to project and many of the potential issues can be reduced by good communication and stakeholder engagement. However, it is quite common for the contract schedule to:

- Be developed early in the contract period, often within 28 days of the contract start date
- Be defined as the intended way of working
- Be used as the basis for measuring performance, and
- Require any proposed changes in the schedule to be approved by the client.

The benefits expected from this approach focus around a perception of certainty that the schedule defines how work will be accomplished and the consequential reduction of risk to the client. The completed schedule allows the critical path and float to be calculated and based on these calculations, the effect of progress and delays can be assessed provided the works are proceeding generally in accord with the plan. There is also an assumption the contractor is prohibited from making changes to the schedule that may impose additional liability on the client or help the contractor avoid liability. Problems arise when the project is no longer working to the plan.

The limitations of CPM

CPM theory works in the right situations and can be forced to fit most other projects, but there are major issues. These can be divided into capability issues and consequential issues.

Capability issues refer to the skills used to develop, review and implement the schedule. They relate to the technical capabilities of the tools, planners and reviewers. Some of the issues include:

- **Network structures that create illogical outcomes**. The components used to create a CPM schedule are simplistic representations of the real world. They can be arranged in ways that create results that are contrary to normal expectations, for example reducing the duration of a critical activity extending the overall project duration.

- **Arbitrary processes for levelling resources.** The resource leveling algorithms used in most CPM tools treat the activity duration and resource assignment as fixed and will delay activities if there are inadequate resources. In reality it is the quantity of work that is fixed, and there are two interrelated variables, the resources assigned to the activity and the time they need to complete the work (duration). Consequently, the modelling process built into CPM for resource levelling tends to produce sub-optimal results.

- **The CPM network is based on fixed sequence of activities, with pre-set logic links and durations, that describe workflows**. There is no concept of critical resource flows between work areas or of the flexibility of resource assignments. When activities that have been delayed by resource levelling restart, there is no clear indication of what resources were transferred to the activity or what they were doing the previous day.

Cultural issues are more significant. Because the CPM schedule is developed by experts using sophisticated software tools and precise mathematics, there is an unrealistic expectation on the part of some judges, arbitrators and managers that the schedule represents reality. However, at best a critical path schedule is a simplified model that outlines one option for completing the work of the project. Even with the full cooperation of the project team, activity duration estimating is an educated guess about what might happen in the future, activities are arbitrary divisions of the work of the project, and the CPM construct is a gross simplification of the myriad of possible interactions between the scheduled activities.

These inherent characteristics of the CPM modelling process represent a major issue if people around the project expect a precisely accurate statement of the future. They are irrelevant if they work collaboratively to create a useful project management tool. Once the idea of the schedule as an accurate control tool is abandoned, paradoxically, the schedule can become an extremely useful management tool. In a complex world the schedule can be used as:

- An effective planning tool to help people engage in conversations focused on optimizing future actions
- As a motivator to inspire the performance of team members
- As an effective communication tool to coordinate actions and assist proactive collaboration.

To succeed in this role, the schedule needs to be flexible, dynamic, responsive and easy for the team members to understand – the schedule should be both useful and used.

The degree of flexibility needed to make the schedule useful is at the centre of the challenges to using CPM. Where the physical nature of the project, and irreversible management decisions limit the options to a single sensible way of undertaking the work of the project, the CPM approach to project controls is both useful and effective. In this situation, schedule quality assessments, skilled schedulers and management engagement can reduce or eliminate the problems outlined above. But the way CPM requirements are built into most contracts assumes there is only one way to undertake the work and is an attempt to minimize risk to the client. This certainty is achieved by eliminating the opportunity for innovation and improvement as the situation changes during the course of the project.

The nature of both soft and distributed projects means there are always alternate ways of working available to the project team and achieving an optimum project outcome requires processes that adapt and change the planned sequence of working as the situation of the project changes. In these circumstances the CPM scheduling processes are far from ideal. While in theory it is possible to keep reconstructing the schedule, this is far from ideal and is prohibited under many contracts.

Unfortunately, vested interests try to paper over these problems. Change is always uncomfortable, and people and organizations with a significant investment in CPM as a one-size-fits-all process include scheduling software developers, trained CPM scheduling practitioners, lawyers, and claims experts.

Classifying Projects for CPM

The suitability of CPM for use on a project depends on the degree of flexibility in the way the work to produce the project's deliverables can be accomplished. Constraints on the choices open to project managers depend in part on the physical design of the work, in part on procurement and other leading decisions (many of which are irreversible), and in part on management choices. There are no hard boundaries between these classifications but most projects can be expected to generally conform to one of the four classes outlined below.

1. Physically constrained – there is only one viable work sequence

This class of project is typically found in the engineering and construction industries. While there may be significant flexibility during the design phase, once the design is locked in, the design and laws of physics dictate the sequence in which the work will be undertaken.

For example, there are several different ways to construct a railway tunnel, but once the design has been optimized, for example, using a single TBM, working from one 'launch pit' the design dictates the sequence of work.

The CPM paradigm is ideal for this type of project.

2. Practically constrained – management has agreed the one best work sequence

This class of project is also typically found in the engineering and construction fields, but can also be seen in projects that involve significant integration with other projects and/or external stakeholders. Once the project management has agreed the intended sequence of work, other projects, asset owners, suppliers, and/or stakeholders rely on the work progressing in the planned sequence. Change in the sequence is possible, but is likely to be difficult to implement and expensive.

For example, the upgrading of signalling and communication systems on a railway line will typically involve several track possessions. Each possession has to be planned months in advance, and all of the new equipment to be installed in that specific section has to be manufactured, tested, and delivered prior to the rail line being shut down and handed over to the contractor to upgrade that section. Resequencing is possible, but likely to be time consuming and difficult.

The CPM paradigm is ideal for this type of project.

3. Overarching constraints – there is a required overall sequence of working, with a degree of flexibility in the way the detailed work is performed to achieve the overall objectives

This class of project is surprisingly common and encompasses most soft and distributed projects (see below). An overall sequence of works may be required, but some, or all, of the detail can be accomplished in almost any sequence. While there may be sensible or desirable sequences of work at the detail level, these can be changed relatively easily.

Class 3 projects exist on a spectrum ranging from projects where there really are no practical constraints on the sequence of working (but you still need to set up the project and close out the project on completion), through to projects where there are significant overall constraints, but there is still flexibility in how the short-term detailed work is sequenced. Three typical examples are:

Example one, a software project may require the MVP (minimum viable product) at release 1, the full financial capabilities at release 2, the stock management capabilities at release 3, and other user enhancements at release 4. Within this high-level roadmap (which may be a contractual requirement with fixed delivery dates), the project team chooses what to build, when, and may choose to use scrum, Kanban or some other agile approach to the development of the product.

Example two, a wind farm requires its connection to the grid and substation to be operational before any electricity can be generated, and also requires all of the wind turbines to be operational before reliability testing, but the construction of the individual wind turbines can occur in almost any sequence (this is discussed in more detail below).

Example three, replacing 600 asbestos-cement telecommunication pits in a suburb with new plastic pits. The high-level constraints are training the workforce to handle hazardous materials, sourcing the replacement pits and arranging to dispose of the asbestos waste. Once these factors are in place the work can be undertaken in almost any sequence, there may be desirable work patterns but these can be changed as needed. Then once all of the pits have been changed there will be some clean up and shut down actions required.

The CPM paradigm may be useful at the high level in a Class 3 project, but has significant limitations at the detail level.

4. Arbitrary constraints – there is no required sequence of working (as in Class 1 or 2), but management has decided to impose a detailed sequence of work as a matter of choice

This type of project would be a 'Class 3 project' if the unnecessary schedule constraints at the detail level are removed. Class 4 projects typically occur as the result of management habit or because of a contractual impost:

- Many standard forms of contract require a detailed CPM schedule to be developed and approved within the first few weeks of the contract period, this requirement is also common in bespoke contracts

- The perception among some managers that a detailed plan provides control.

These two factors can be mutually supportive and result in the creation of a detail schedule for the whole project regardless of its usefulness.

The schedule may be useful if the project team 'works the plan', but its existence limits options for both problem solving and process improvement. This concept of a predetermined plan that must be followed becomes counterproductive once the project's work starts to be performed without reference to what is seen by the project team as an out-of-date, or irrelevant plan.

The CPM paradigm is imposed for little or no practical benefit.

Classification summary

CPM was initially developed and used in the engineering and construction industries which make up the bulk of projects that would be categorized as Class 1 or Class 2 in this classification system. It is therefore hardly surprising the use of CPM is still strongly supported after 60 years.

However, for the reasons discussed below, CPM is far from ideal for planning and scheduling the work in Class 3 and Class 4 projects. The only difference between these two classes is that in Class 4 projects contract requirements and/or management tradition is trying to force fit CPM onto a project where its use is likely to be counterproductive.

Defining and Managing Soft and Distributed projects

The general concept of a project has been understood for some time; our preferred definition is: *A temporary organization established to accomplish an objective, under the leadership of a person (or people) nominated to fulfil the role of project manager*. Regardless of the definition you prefer, projects are temporary, involve a team of people, and are created to deliver an output, outcome or objective. But, many of the projects that fit into the Class 3 and/or Class 4 classification above cannot be effectively controlled using a detailed CPM schedule, or other deterministic approaches that have been considered the accepted way of controlling projects for decades.

There are two general types project that are disadvantaged by imposing detailed deterministic scheduling, *soft projects* and *distributed projects*, these general types are defined below, together with the management approaches that seem to offer the best opportunity to improve outcomes.

Soft projects

Soft projects are those where the final result is not defined by the creation of a tangible asset[4]. There may be some tangible deliverables produced, but the value generated by the project is in the new capability, concept or situation that is created. For example, a new architectural design may be printed onto paper but the value is the design concept (which enables a new structure to be built), not the physical plans.

The concept of a soft project extends well beyond software development to encompass projects focused on change management, business process improvement, service delivery and design development. Any project that is set up to deliver an intangible benefit, and involves a degree of creativity and/or stakeholder engagement as part of the development process can be considered soft. But soft does not mean easy to do or manage!

The key challenge in this type of project is the difficulty in knowing or predicting human reactions and behaviours. You cannot set a precise time on how long it will take:

- To have a group of stakeholders accept a new idea or way of working
- For an expert to solve a process problem, or
- For an elegant and acceptable set of designs to be created.

The key characteristic of a soft project is that the final solution can take many forms – different project teams will create acceptable outcomes using quite different techniques and solutions.

Because of their nature, soft projects benefit from using a flexible approach to manage work that adapts to the emerging knowledge and needs of the project team and their stakeholders, to optimize stakeholder engagement, the work of the team, and enhance the output. This flexibility may include agile, iterative, and/or incremental approaches to the creation of the desired deliverable or outcome.

Changes to a soft project to enhance the value delivered to its stakeholders are generally easier to implement than in projects that are classified as hard[5]. Most of the components or modules built into the final soft deliverable can be changed relatively easily as more information becomes available. For example, the need to enhance a software module to

[4] **Note:** The differentiation of hard and soft projects is imprecise. We suggest the primary differentiation between the two, is the various components of a hard project have to literally fit together, this required a detailed design to be finalized for each element of the project, before its components can be procured and assembled. Whereas the detailed design of components in soft projects can be done as part of the work involved in developing the element. For more on this see: https://mosaicprojects.wordpress.com/2023/01/21/hard-v-soft-projects/

[5] As well as producing a tangible product, a key characteristic of a hard project is that the majority of the work is dependent on a finalized design being complete for each element of the project, prior to work starting on that element.

increase its capacity may involve some rework and testing but the change is relatively easy to make. In contrast, if there is a need to increase the load bearing capacity of a structural foundation after it has been built, the change usually involves extensive demolition of the work done to date, followed by the construction of a new higher capacity foundation, a very time consuming and expensive process.

Where the nature of the project requires an overall flow of work to be implemented, either a CPM schedule, or more usually a bar (Gantt) chart, can be used for this high-level road map. However, other more agile techniques are normally used for lower levels of control

Agile approaches:

Agile is the management approach of choice for most soft projects. There are many different forms of agile involving different tools and techniques such as Scrum, SAFe®, DA, and Kanban. However, across all of these different methodologies, the essence of agile remains – intelligent flexibility; the people doing the work choose what to work on next and scope changes are welcome as long as implementing the change increases the overall value of the deliverables to the project stakeholders.

The core elements of an agile approach are the project team and stakeholders develop a backlog of work to be done to achieve the desired objective, and then at regular intervals the project team select the items to do next from the list. The underlying assumption is a committed and skilled team actively involved in the work are the best people to decide what should be done next, and the best way to do it.

Note: Scope may, or may not, be variable in an agile project. The Agile framework encourages change, but where agile is being used on a fixed price project to deliver a scope of work defined in a formal contract, change control processes are needed the same as in most hard projects.

Distributed projects

Distributed projects are a subset of hard projects that exhibit two dominant characteristics: a significant portion of the work is comprised of a series of physically separated units that are similar or identical in design; and the need for the different units to be built in a specific sequence is either non-existent or minimal. Some examples include:

- Infrastructure upgrades (eg, removing asbestos telecom pits – see discussion above)
- Hardware upgrade / replacement (eg, replacing 2000 computers in a business)
- Some social housing projects (eg, building 50 new dwellings on 50 separate building blocks)

- Normal road maintenance work across an area controlled by a local authority.

The key characteristics of distributed projects are:

- The work sequence is easily changed for at least some of the project deliverables
- Management's focus should be on optimizing resource workflows
- Control is based on measuring key resource productivity
- Access to the next task for each resource is based on the necessary prerequisites being completed rather than following a predetermined sequence of jobs.

In this type of project, it is common for each of the components needed to complete a job to be standard across many of the units being built, and consequently can be used as needed. This means the distributed work can be planned in almost any sequence, and that sequence can be easily changed at almost any time.

Therefore, the primary consideration in planning a distributed project should be optimizing resource workflows, and the consequences of re-sequencing are not based around traditional CPM logic, rather the potential for loss in resource efficiency which is much more difficult to assess and measure.

Developing efficient workflows still needs appropriate planning and preparation at each location. This includes ensuring everything is ready to start at the next location, relocation and travel distances are optimized, and the work is done in the correct sequence at the location.

Understanding and managing the constraints that affect the work is the key management challenge. Some constraints affect the whole project, these include:

- Various approvals needed to start work being in place such as planning, design, and safe work
- Resource and supply contracts or agreements in place and the delivery of materials to site.
- Some constraints affect the ability to complete the work at a specific location such as:
- Access to the specific work area
- The availability of resources to undertake the work
- The required sequence of working at the location.

Depending on the nature of the distributed project, constraints will exist in a spectrum from almost none to significant limitations on the sequence in which the distributed elements can be built, however, the key management challenge is always balancing and optimizing resource usage and work flows.

Only plan in detail what you know in detail

There is a long tradition in the construction/engineering industries of flexible short-term planning, even on Class 1 and Class 2 project types. The CPM schedules provide the overview of what's needed to be done in what order, but these contract schedules rarely break down into the work sequences required in individual rooms, etc. For example, on a typical high rise building the CPM schedule is likely to schedule finishes on a floor-by-floor basis and set the overall sequence of work, other planning processes are needed to coordinate the work room-by-room across each floor.

Some of the detail and short-term planning processes used in construction/engineering include:

- From the 1950s, the concept of schedule levels had an overall project schedule, possibly subdivided into more detailed area or zone schedules (both typically using CPM), supported by detailed short-term look-ahead schedules. The short-term schedules were typically produced as bar charts using input from the trade supervisors. The look-ahead period would be either two weeks, with the schedule updated weekly, or a month, with the schedule updated every two weeks.

- Rolling wave was developed in the 1960s. It is the process of increasing the detail in a schedule as more information becomes available. The distinguishing feature is timing – rolling wave expands summary activities to the level of detail needed for the work you are going to do in the next few months. This process is repeated at regular intervals, the expansion of detail rolling through the project schedule rather than a fully detailed schedule being produced at the project commencement.

- Schedule density is a more structured approach to implementing the rolling wave concept. It defines specific timeframes for increasing the level of detail and suggests the organizations and people involved in the work should be involved as each increase in detail is added.

- The Last Planner System (LPS) is another approach to rolling wave developed by the Lean Construction Institute intended to increase worker productivity and accountability through tight scheduling and detailed group planning. The first step is to create an overall master schedule, then a timed series of more detailed phase schedules. Based on the current phase schedule 'make work ready' meetings occur several weeks before a task is schedule to start with a view to removing any constraints or road blocks that could prevent the activity starting and weekly check-ins assess actual progress. As with schedule density, the people and organizations (subcontractors and suppliers) responsible for actually undertaking the work are expected to be involved in the planning and then to achieve their planned commitments.

These concepts can be adapted to the control of distributed projects.

Common characteristics

The common factor in the approaches described above is the people doing the work decide on the next set of activities to undertake at regular, relatively short, intervals. The decisions are made based on the current situation, any overall project requirements or road map, and any identified constraints or specific sequencing issues. The process is repeated until all of the project work is complete.

In this situation the concept of a critical path schedule is meaningless! The planned sequence of working can change every couple of week and change is encouraged to maximize efficiency, embed lessons learned, and deal with problems. This agile approach to completing the work of a project has two consequences:

a) A CPM schedule cannot be used to predict the time needed to complete the project; there is no predetermined sequence of activities and therefore no possibility of calculating a critical path through to completion. However, there is a measurable backlog of work to be completed.

b) Without a realistic CPM schedule, most of the standard ways of contemporaneously assessing delay claims cannot be used, for example both the Delay and Disruption Protocol and AACEi RP 29R-03: Forensic Schedule Analysis require a CPM schedule for predictive delay analysis. This limitation also has the effect of making the extension of time and delay assessment provisions in many contracts unusable.

A potential solution to (a) above is to develop a volumetric approach for assessing project completion analogous to Earned Schedule; where the time needed to complete the remaining work is scaled to reflect the productivity achieved to date (with appropriate consideration of available resources).

A potential solution to (b) above is to reframe the way work is planned focusing on the need to keep the controlling resource fully occupied on productive work. If there is a delay that causes the controlling resource[6] to be delayed, this delay can be assessed

[6] The concept of a controlling resource is based on the paradigm that one resource or class of resources control the work through to completion. In a wind farm, this is typically the main crane undertaking the tower erection. In an IT project the people developing the end product.

and an appropriate extension of time (EOT) agreed. Delays to other resources can be assessed using a process similar to Critical Chain, did the delay to the non-controlling resource flow through to cause a delay in the work of the controlling resource?

Ideally the two solutions proposed above should be incorporated in a single control paradigm.

Building Wind Farms

Note: The objective of this section is to place the issues outlined above in the context of a specific type of generic project rather than offer a planning solution for every instance of an on-shore windfarm.

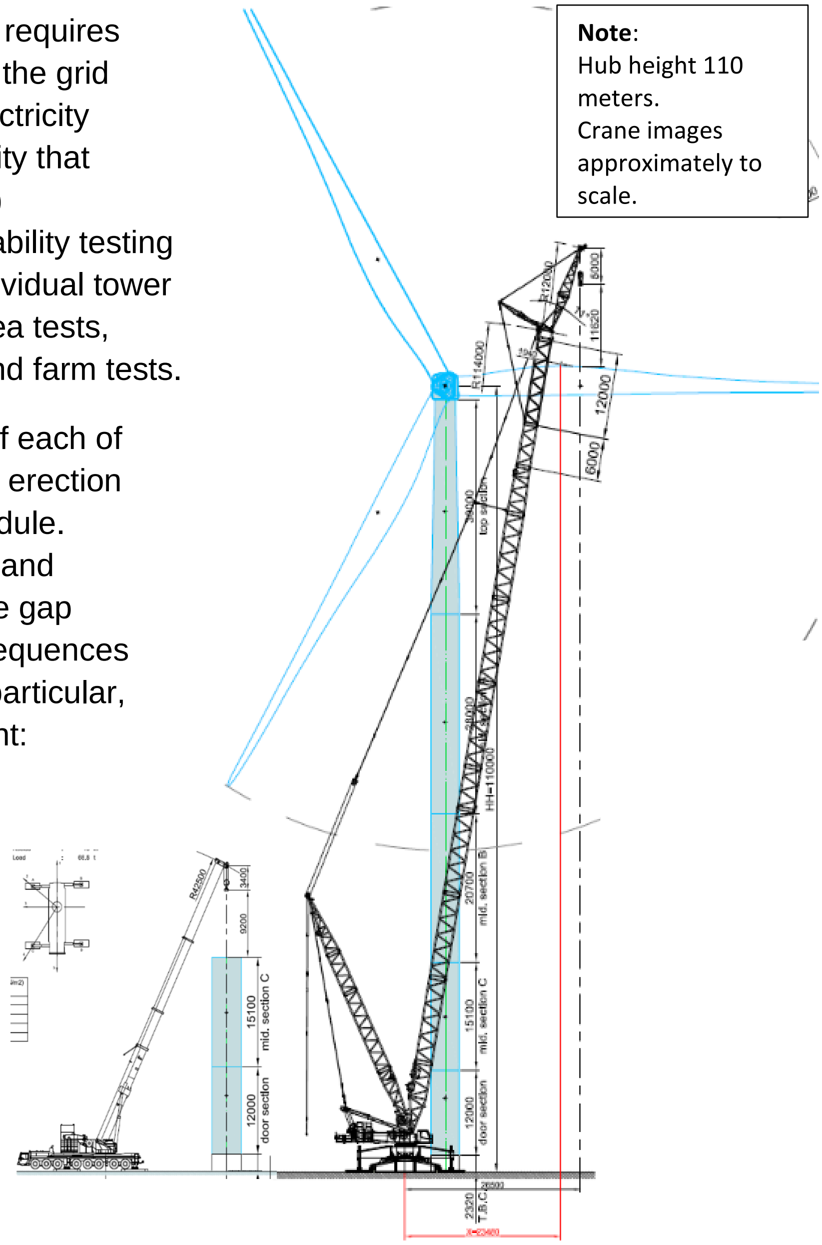
Typical wind farm projects present a complex series of schedule and control problems, some sequences are mandatory, other sequences of work are almost unconstrained.

The big picture mandatory sequences typically include:

- The substation and grid connection must be complete before any electricity generation can start
- The turbines and towers need to be designed, ordered and delivered before erection can start (usually about 1 year)
- Civil engineering and foundations need to be complete before tower erection can start in an area including installing the collector mains back to the substation
- All towers need to be complete before the overall wind farm reliability testing can start.

Mandatory sequences are also present at the detail level, there is likely to be one best way to build and commission the substation and the transmission line (both Class 2 projects in their own right). The construction of each wind turbine also needs to follow a defined sequence, before the main erection can start, the tower foundations, cabling, and construction access need to be complete, then the turbine components need to be either delivered to the location, or available if a 'just in time' lifting process is being used. Once these prerequisites are in place, the tower erection sequence is mandated and typically involves the coordinated deployment of a series of crews:

- First, the lower tower sections are installed by one crane crew (this lower section can be capped and left)
- Then the upper tower sections and nacelle are lifted by the primary crane crew, followed by the hub and blades
- Electrical and mechanical fit out of the structurally complete tower is next, followed by

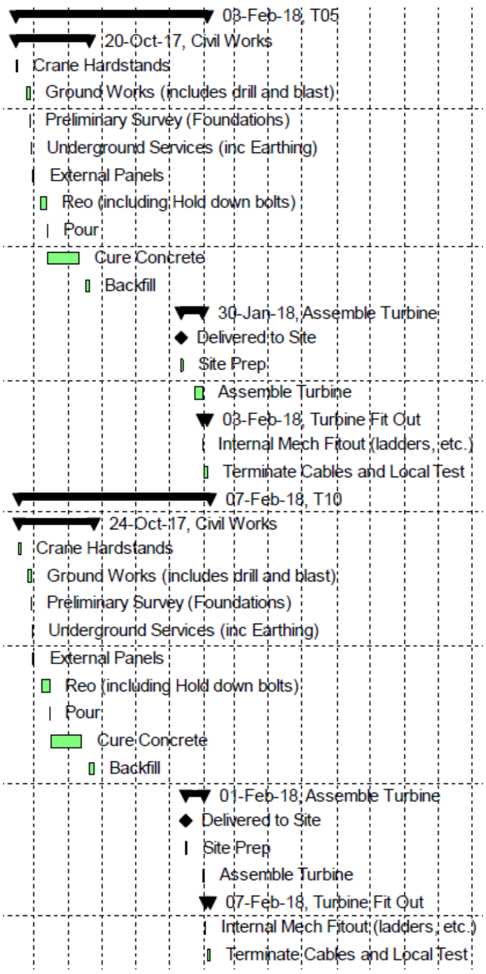


- Commissioning which requires connection through to the grid (the generated HV electricity is a valuable commodity that has to go somewhere)
- The final phase is reliability testing this starts with the individual tower then progresses to area tests, followed by the full wind farm tests.

The different speed of working of each of the crews involved in the turbine erection tends to create gaps in the schedule. There is in effect four workflows and provided there is a sufficient time gap between the crews, their work sequences do not need to be the same! In particular, weather delays are not consistent:

- Civil engineering, offloading, and transport are only delayed by extreme weather events and can start as soon as the windfarm design is adequately progressed
- Tower base erection is only affected by high winds and other extreme weather
- The main tower erection including the nacelle and
- blades is seriously affected by wind; even moderate winds can stop the lifting and wind farms are built in windy locations
- The mechanical and electrical fit out is largely immune from weather effects but constrained by the main erection progress
- Commissioning follows the fit out, but electrical safety is also a key constraint:
  - Within each tower
  - Within each collector group
  - Overall.

Most of the CPM schedules for wind farms that I have seen are similar to this program extract and focus on the tower build sequence assuming all of the crews will flow from tower to tower in the same sequence and need similar times to complete their work.



Different management approaches are needed if the work is considered as a 'Class 3 – Distributed' project:

- Civil works need to be focused on allowing efficient deliveries and being clear of an area before tower erection starts to minimize traffic congestion
- Both offloading and base erection crews need to work efficiently and then move off site as soon as practical, they both incur high daily costs
- The primary focus is to keep the critical primary crane working efficiently
- Fit out crews need to be sized to match the average erection times time the main crane needs per tower including wind delays, not net erection times

Aspects that are not logically constrained, subject to the necessary prerequisites being in place include:

- Any tower component can be used on any wind turbine
- Foundations can be constructed in any sequence
- Turbines can be erected in any sequence
- Commissioning can be performed in any sequence

The key consideration is the efficient use of resources not an arbitrary build sequence. In particular, the various stages of tower assembly can be undertaken in different sequences provided following crews are not inconvenienced; as stated above the two considerations are to first complete the civil works, offloading and tower base assembly as quickly and efficiently as possible then remove these crews from site, and most important, keep the primary erection crew working efficiently.

In summary:

- Crew production rates vary significantly between the different crews
- Weather delays affect each of the crews differently, the primary crane can have 300% more downtime than other crews
- Crew access to a tower is based on the prerequisites being completed, not a predetermined arbitrary sequence
- Crew handovers need to consider average rates (after delays)
- Traditional critical path scheduling is less than optimal – flexibility is needed

Windfarm conclusions

When planning a windfarm, the big picture logic matters (civil works, substation, towers, commissioning, etc.), an overarching CPM schedule is ideal for this. CPM is also a good solution for the planning of the transmission line and substation builds, these are both ‘Class 2’ projects in their own right.

The construction sequence for the individual turbines is far more flexible, the primary constraint is the internal logic for each tower: foundations, deliveries, lower tower, upper tower, fit out. Different crews perform each stage making handovers important which requires proper logistics and the completion of each stage to 100% with adequate time buffers between the crews.

The key to success is maximizing the efficiency of each crew so as to minimize their time on site; the standing costs for each of the crews are significant. However, there is always the need to balance the big picture with individual resource utilization, what matters is starting the final overall commissioning as soon as practical. Maximizing resource efficiency within this overall objective is a day-to-day process on 3 or 4 different work faces. The key is keeping the slowest resource crew working to 100%, this is usually the primary erection crane crew, which means dealing with the inevitable delays and disruptions proactively.

Critical path schedules cannot deliver the required sophistication, adaptations of concepts such as Last Planner or Schedule Density, working with the people doing the work on site is likely to be far more effective. This approach will allow generation to start progressively and early, while keeping the other crews as close to 100% effective as possible to minimize their time on site. Flexibility and agility are the keys to minimizing costs!

Recommendations for Refocusing Management and Control in Class 3 Projects

Practical considerations

For most soft and distributed projects (Class 3), optimum productivity is achieved by allowing the project team to work out the best plan for the next 2 to 4 weeks on a regular basis, using an appropriate framework such as Scrum, Last Planner, etc. The options open to the team are constrained by the overall plan for the project which may be a CPM schedule, and other contractual, physical, or safety requirements where they exist. These constraints can vary from almost non-existent to significant, and their effect needs to be understood by the project management and team.

However, when it comes to dealing with issues and problems, removing impediments and road blocks, and keeping the critical resources working to 100% of their capability, arbitrary choices made months ago are unlikely to be as effective as decisions made by an informed and motivated team engaged in the work. The management challenges are:

- To build and motivate the team
- Empower the team to be successful, and
- To remove as many unnecessary constraints as possible
- While maintaining focus on the big picture requirements the project was created to deliver.

These are the core concepts in the Agile Manifesto, Last Planner, and Schedule Density, none of which are new ideas! But you cannot be agile and adaptive based on a highly detailed CPM schedule created within a few weeks of the project's commencement. A different management paradigm is needed.

Legal considerations

While the ideas outlined above offer major opportunities for improved outcomes in soft and distributed projects, you cannot ignore the legal and contractual considerations. Unfortunately, most current contracts, particularly in the construction and engineering industries, are incapable of dealing with an agile or adaptive approach to management. But, developing new contracts and assessment paradigms will not be easy. Assessing delays and disruption to the resources working on a distributed project is likely to be more accurate, but is more complex.

The *Delay and Disruption Protocol*[7] already separates the cost of disruption from the entitlement to EOTs, but to properly assess these factors, consideration of the planned time for each crew engaged in the project is needed, together with processes for assessing the effect of delays on the different work crews or teams. This problem affects:

[7] Society of Construction Law (SCL) Delay and Disruption Protocol 2nd Edition: February 2017: https://www.scl.org.uk/sites/default/files/documents/SCL_Delay_Protocol_2nd_Edition_Final.pdf

- All distributed projects (not just wind farms)
- All soft projects where development is done in sprints or iterations (not just IT)
- Other hard projects using lean construction and last planner techniques.

At the current time, there are no generally recognized techniques for assessing disruptions that affect the efficiency of resource crews or teams, where the imposed inefficiency may flow through to a project delay. Determining the cost of the disruption is difficult, as is determining the consequential delay (if any).

The approach embedded in the Agile Manifesto is to assume the client, end user, and delivery team work together to proactively solve these problems. This can translate across to engineering projects via various alliancing and partnering contracts (pain share gain share) but while this is desirable, it is not common.

Cooperative problem solving is certainly a good idea if it works, but ultimately any unresolved dispute will be determined based on the contract and the law. Unfortunately, most traditional contracts are not fit for purpose when applied to Class 3 projects and even when a detailed CPM schedule is imposed on this class of project (shifting it to a Class 4), the CPM rarely provides an acceptable outcome.

To overcome these shortcomings, the only effective management approach is to:

- Keep rigorous and detailed records of everything for use in formal dispute processes after the event
- Provide all of the notices and determinations in the time required
- Try and sort the mess out afterwards by negotiation or mediation, and if this fails
- Develop an accurate ‘as-built’ schedule and then apply appropriate retrospective delay assessment techniques.

There is a lot of work needed in this area including contract improvements focused on efficient risk allocation, and the developing protocols for dealing with the issue of contemporaneously assessing delay and disruption pragmatically within existing forms of contract.

Conclusions

Many projects defined as Class 3 and Class 4 above do not conform to CPM theory, the work can be planned in almost any sequence and that sequence can be easily changed at almost any time. New ways of thinking and working are emerging, and need supporting by better contracts and legal processes.

The primary consideration in planning Class 3 projects is optimizing resource flows, and the consequences of re-sequencing are not based around traditional CPM logic, rather changes in resource efficiency which is much more difficult to assess and measure. Particularly when you need to separate productive efficiencies under the control of the contractor from disruption caused by re-sequencing.

This paper has identified the issues associated with managing Class 3 projects and has identified practical ways to refocus management and controls practices to optimize outcomes. Two supporting papers will look at:

1. Implementing a robust system for reporting progress and predicting completion in agile and distributed projects that can be applied to any class of project (planned publication May 2023).
2. Assessing delay and disruption in agile and distributed project where the use of a CPM schedule is not viable (planned publication June 2023).

About the Author

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Patrick Weaver, PMP, PMI-SP, FAICD, FCIOB, is the Managing Director of Mosaic Project Services Pty Ltd, an Australian project management consultancy specializing in project control systems. He is a Fellow of the Chartered Institute of Building, Australasia (FCIOB) and a Fellow of the Australian Institute of Company Directors (FAICD). He is a member of the PMI Melbourne Chapter (Australia), as well a full member of AIPM, and the Project Management College of Scheduling (PMCOS).

Patrick has over 50 years' experience in Project Management. His career was initially focused on the planning and managing of construction, engineering and infrastructure projects in the UK and Australia. The last 35 years has seen his businesses and experience expand to include the successful delivery of project scheduling services and PMOs in a range of government, ICT and business environments; with a strong focus on project management training.

His consultancy work encompasses: developing and advising on project schedules, developing and presenting PM training courses, managing the development of internal project control systems for client organizations, and assisting with dispute resolution and claims management.

In the last few years, Patrick has sought to 'give back' to the industry he has participated in since leaving college through contributions to the development of the project management profession. In addition to his committee roles, he has presented papers at a wide range of project management conferences in the USA, Europe, Asia and Australia, has an on-going role with the PGCS conference in Australia and is part of the Australian delegation to ISO TC258.

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