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The Project Governance and Controls Annual Review (PGCAR) showcases interesting and practical academic papers focused on enhancing the governance and practice of project, program and portfolio management in the Australasian region. Each annual update is published in the months following the Project Governance & Controls Symposium held each year in August, in Canberra; and includes papers received in the preceding year.

To submit your paper for review, see: https://www.pgcs.org.au/academic-papers/

PGCS PROJECT AND PROGRAM MANAGEMENT SYMPOSIUM
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The Project Governance and Controls Symposium (PGCS) is designed to enhance the connection between project and program management, governance and controls. Project management cannot operate effectively without the support of senior management and the information from effective project controls. Frank and fearless reporting of status and issues cannot be assumed if the middle levels of management have the capability to restrict negative information. Conversely, executive management decisions depend on accurate and realistic assessments of risk, schedule and cost. Creating a culture where this type of information is not only available but accepted and used properly is the key governance issue within the project, program and portfolio domain.

For more information on this year's PGCS, see: https://www.pgcsymposium.org.au/

The Walt Lipke Awards

The Project Governance and Controls Symposium (PGCS) sponsors the annual Walt Lipke Award in honour of Mr Lipke's contribution to enhancing the governance and control of projects world-wide.

Walt Lipke (brown suite – shown here presenting the 2017 award at PGCS) is the creator of Earned Schedule, which extracts reliable schedule information from earned value data (resolving the long-standing error in the calculation of SPI and SV). Earned Schedule is freely available to the project community from: http://www.earnedschedule.com/

The PGCS Walt Lipke award is open to the authors of papers submitted to the PGCAR journal since the close-off of the previous year's award, that have been accepted for publication, and are available for presentation at the PGCS Symposium in Canberra. The winning papers are selected based on:

- **Originality**: a new or innovative concept
- **Practicality**: the usefulness of the concept in the management of projects, programs and/or portfolios in the Australian context, and
- **Quality**: the academic merit of the paper.

Walt Lipke Award Winners

2017 Mr. Peter Slay

2018 Dr. Raymond Young

2019 Dr. Shankar Sankaran

2020 Mr. Munir Ahmad Saeed

2021 To be announced at PGCS 2021, Canberra.

For more information on the Walt Lipke award (and to read previous year's winning entries) see: https://www.pgcs.org.au/academic-papers/#Walt

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Editorial

This 3rd edition of the Project Governance and Controls Annual Review (PGCAR) has been published in extraordinary times; we are all hoping 2021 will allow some return to normality.

The papers in this edition have been drawn from a range of sources and include a mix of academic, and industry papers as well as an excellent guide to advanced project scheduling by Chris Carson. As always PGCS is now open to receiving papers for 2021. While we are happy to accept all papers for publication (the only criteria are quality and relevance) to be eligible for the Walt Lipke Award and its $1000 cash prize, you do have to be prepared to present your paper at PGCS 2021 in Canberra.

This year's award winner, Munir Ahmad Saeed, will still receive his prize and the annual award to retain despite the PGCS 2020 Symposium being cancelled as a consequence of COVID-19. The good news is we are working towards a 'COVID-Safe' event in 2021 – details will be updated on the event website at https://www.pgcsymposium.org.au/ as planning proceeds.

In the meantime, you are invited to register for our free PGCS monthly webinar series, which has been developed for the CASG and the Defence Program and Project Management Community. To find out more and register see: https://www.pgcsymposium.org.au/webinar-series.html

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Benefits Management – Between Dreams and Realities

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Abstract

In the Project Management (PM) literature Benefits Management (BM) has been highlighted as the real purpose for the implementation of projects both in the public and private sectors. PM literature has been discussing project success since the 80s but since 2000, the focus of project success debates has turned to benefits realization. Benefits realization takes the project success debate from outputs to outcomes, inviting the senior management to shift their focus from project delivery on time and cost, to outcomes and benefits to bring real value to the organization. But the current literature on benefits management, is mainly normative and aspirational, therefore most of the debates in PM literature, are about what should be done, rather than what is happening in practice on benefits management. To fill this gap, recently, a doctorate study research was conducted 45 interviews in six public sector organizations of the Commonwealth government. The emerging research findings highlight a gap between dreams and realities, aspirations and practices in benefits management in the Australian public sector. This research found several factors behind poor benefits realization such as a lack of accountability for benefits, mandatory requirements to report on benefits realization, focus on delivery on time and budget and poor governance and leadership by the senior executives. This article briefly compares what the aspirations of BM literature and the current BM practices in the public sector organizations.

Keywords: Benefits Management, Benefits Realization, Governance, PMO, Benefits Owner, Framework

Introduction

Project success has frequently been discussed over the decades in the PM literature and achieving project success has been the major aim project practitioners. Project success debates also captured the imagination of researchers, as Ballard et al (2014) state that project success, as an area of academic interest, appeared in the 1980s, when researchers started investigating project success beyond scope, cost and time, and leading this debate, Pinto and Slevin (1988) published a list of 10 project success factors, which is now considered a pioneering work on this issue (Ballard 2014). Since the last decade and a half, the project success debate has moved from project outputs to outcomes and benefits realization. Bradley (2010) is credited to have introduced the concept of benefits management, initially and later, he rebranded it as benefits realization. Project Benefits Management (BM) has assumed significance as a key success criterion in addition to delivery of projects within scope and on time and cost. Project Management literature has been increasingly arguing for focusing on project outcomes rather than project outputs. An extensive literature conducted for this study highlights that BM literature is more aspirational and normative, and it does not reflect current BM practices in the public sector organizations. There is a need to fill in the existing gap between research and practice in benefits management and our study endeavours to bridge this gap and this article is the first step towards this objective.

Literature Review:

Benefits management as a new criterion for project success, despite having been introduced nearly two decades ago, had a slower uptake by the practitioners in various industries employing project management, possibly due to the fact that Project Management (PM) methodologies and training were all centred around project delivery on time and cost and a paradigm shift such as benefits management had to fight the inertia of the existing practices. Zwikael (2016) states that PM literature and relevant PM standards overwhelmingly focus on the need for providing project deliverables within the triple constraints and he states this focus ignores the significance of project effectiveness in delivering project benefits or value to stakeholders. Breese (2012) states that IT industry took the lead by adopting benefits management to evaluate big investments in technology, but benefits management is equally applicable to other disciplines as well. Mossalam and Arafa (2016) claim that benefits management has now become a key factor in project success. APM-Special Interest Group (2017) survey results indicate that the group members reported increasing awareness in their organizations, that benefits management must be an integral part of project management practices, particularly at P3M3. Marnewick (2016) also calls for integrating benefits management into the project life cycle and argues for necessary amendments to PMBOK standard by making benefits management a new knowledge area. Badewi (2016) states that there is a co-relation between project management and benefits management, therefore both should be woven together under a single governance framework for enhanced project success. The role of project poor governance with regards to benefits management has been criticised by researchers. Saeed et al (2019) state that 80 percent of research participants expressed dissatisfaction with project governance in the public sector organisations, as project governance is focused on the delivery of outputs rather than outcomes. At times people in project governance are unaware of their roles and responsibilities and there are no reporting requirements for benefits management in project status reports to the governance boards (Saeed et al 2019). For effective benefits management, the role of benefits owner has been highlighted as critical by many researchers such as Peppard et al (2007) argues that benefits owner should be identified at the outset and the owner should be accountable for benefits realization. Saeed et al (2019) state that research participants have unanimously called upon the benefits owner be assigned to operations/business managers, whose department would be the end user of the project product/service. Our research indicates that in the public sector organizations, mostly a Senior Responsible Officer (SRO) is nominated as a benefits owner. SRO is normally a senior executive of Band 2 or 3 level (www.finance.gov.au), who is a division head and is accountable for a number of projects running in a program. However, the role of benefits owner has become ineffective due to the lack of mandatory requirements and accountability for benefits realization during the post project delivery period of 12 to 18 months.

The BM literature has not specifically discussed the enablers and inhibitors of benefits management, except Coombs (2015) who highlights enablers and inhibitors for information system, but these are of technical nature rather than cultural and organizational factors impeding benefits management. Coombs states that technical inhibitors include matters such as poor design of reports and low system response in function response time. Similarly, technical facilitators are training on the use of system, mapping and redesign of existing processes. Some other authors such as Young et al (2017) highlight top management support, change in organizational culture and effective communications, as BM enablers. Similarly, Eduardo and Serra (2017) also identify stakeholders' engagement and effective communication as BM enablers. Young et al (2014) argue that one of the reasons for poor benefits management is the managers' mindset that the benefits will be realised with the delivery of the product. The authors state that programs and portfolios do not deliver strategy and there is a lack of interest in government agencies for project outcomes and benefits management.

BM literature forcefully argues for the adoption of benefits management, as the basis of decision making on project success, it also seeks top management support for the establishment of necessary process, accountabilities, and the integration of BM into the project life cycle. It also argues for an active benefits tracking, measuring and realisation after the project delivery, so that organizations get expected value from investments into projects. However, it raises an important question, how far the industry has been able to catch up with what BM literature has been proposing. This paper compares what literature has been propositioning on benefits management and what is practiced by the industry on ground. This research endeavours to bring research and practice closer by transporting the war stories from the trenches and explains what challenges the practitioners encounter in their efforts to adopt benefits management.

Methodology:

The methodology for this research is qualitative and is based on a case study method. A case study method has been selected due to the inherent ability to answer, 'how and why' questions (Yin 2009, 2014). The case study method is appropriate to explore a phenomenon, which is current, observable, allows interviewing and does not require control over the behavioural phenomenon and focuses on contemporary events. Blomquist et al (2010) argues for research based on 'project as practice' to discover solutions for project managers and managers. This research enhances our understanding of the challenges faced by organizations in benefits management and responds to a call by Blomquist et al (2010) for project as practice, to identify benefits management practices in the public sector organizations. For this research, field data was collected through 45 semi-structured interviews, conducted in six Commonwealth Government departments. The research covered a wide range of issues related to benefits management, but this article is limited to a brief comparison of BM literature and practices in the case study organizations of the Australian public sector. Interview transcripts were analysed to identify codes and emerging themes. Contents analysis method was employed to analyse the data from these interview transcripts. Maxwell (2012) argues that a qualitative research study must specify how data analysis will be carried out and this decision should 'influence and be influenced' by the rest of the design. He specifies three types of qualitative data analyses, such as 'Categorizing Strategy' (coding and thematic analysis), 'Connecting Strategies' (narrative analysis and individual case study analysis) and lastly 'Memos and Display'. A code is "a short word or phrase that symbolically assigns a summative, salient and essence-capturing, and or evocative attribute for a portion of language based or visual data" (Saldana 2012, p 3). Schreier (2012) identifies three strategies for structuring and generating codes, such as Concept driven, Data driven and a Combination of both. Braun and Clark (2014) consider concept driven approach as top down, in which a researcher comes up with a series of questions, concepts and ideas. Braun and Clark also agree that it is near impossible to be completely inductive or deductive. Therefore, Schreier (2012) prescribes a 'typical mix' in which we can initiate with key concepts based on what we already know, by making them into main concepts, as a first step and then add more categories, initially not known. Following Schreier, a mixed method was employed for codes and themes generation, based on the research questions (below) but all the transcripts were read line by line, which resulted in the identification of large number codes and themes. The emerging themes were revised and where possible these themes were merged, based on similarities of meanings, relevance and the third round of revision resulted into 8 final themes. This research started with a hypothesis that BM literature is mostly aspirational and normative, and it aimed at reaching out to the practitioners and find out the dreams of BM literature and the realities of practice.

Following are the research questions of this research:

1. How project benefits realization is being practiced in organizations?
    1.1. What are the current frameworks, processes and practices employed?
    1.2. How project target benefits are formulated and appraised in practice?
    1.3. What is the role of governance in project benefits realization?
2. What are the enablers and inhibitors of benefits realization in organizations?

Results and Discussion:

Table 1: A comparison of BM literature and BM practices in the public sector organizations

What Literature Says	References	What Practitioners Do	Selected Quotes from participants interviews
Benefits in business cases are used to sell the project idea and defined in broad and generic terms involving subjectivity	Aubry et al (2017)	Benefits identified in the business case are at times unrealistic, and do not play much role in decision making on a project proposal. In some cases, benefits are listed in the business case just to tick the box	'In the business case you can promise anything, it does not mean it's going to happen'. 'The benefits don't come into it for decision making so, a project is rarely, if ever approved on their benefits'.
Benefits must be aligned with organization strategic objectives	Marnewick (2016)	Benefits are aligned to strategic objectives in the business case, to meet requirement.	'Strategic objectives are written in such a way that you can align anything to them'
Benefits should be effective (SMART) and comprehensive (involving stakeholders).	Zwikael et al (2018)	Identified benefits are at times unrealistic, unmeasurable and developed in isolation without much involvement of end users	In the business, 'There are no defined benefits that we can even measure when we get them in, because they are generally written by policy folk, who have no project management experience'

Organization do not have the ability to formulate benefits	Chih and Zwikael (2015)	People who develop benefits are from the Policy or Strategy divisions of the organizations and they define benefits as outcomes statements.	'Benefits are identified as feel good statements and client satisfaction is a cliched benefit here' 'For me, the scope is the outcome, and the outcomes is the benefit'. 'They write our business case to the government and they are flawed from the moment they are written because they do not understand benefits'.
Project manager should track benefits along the entire project life cycle	Massalam and Arafa (2016)	Project manager is hired to deliver the project on time and cost, and benefits reporting is not among the responsibilities of a project manager	'Benefits are not the KPI of the project manager anymore and PM's performance is not going to be measured whether or not the PM does benefits realization well'.
The focus of project governance should be extended to ensuring benefits realization	Marnewick (2016)	Governance is focused on outputs delivery on time and on cost	'I think benefits realization is the first cap to go as well when things get tough, they'll take the benefits realization out'. ' I think as a part of the equation where delivery dominates over business, benefits management also suffers. There is no systematic approach, business areas need to lead and articulate benefits.'
Benefits Framework should be integrated into PM processes	(Zwikael and Smyrk 2012, Chih and Zwikael 2015)	Benefits frameworks exist in isolation of PM processes	' I think it's probably fair to say that once you pass the funding decisions, the utilisation of the benefits realisation frameworks has been

			significantly less than I think it would be appropriate'.
There is no consensus whether benefits should be managed at the project, program or portfolio levels	Allen and Saeed (2018) Saeed et al (2019)	In all case study organizations benefits are managed at the program level, benefits are identified at the project level but are managed at the program level, as many projects may be contributing towards one program benefit	'Projects produce outputs and programs produce outcomes and benefits and portfolio generate value' 'benefits should be managed at programs due to a longer life cycle' 'benefits should be managed at the portfolio for providing an organizational view of benefits'
It is more common to evaluate project success on the basis of benefits rather than deliverable on time and cost	Mossalam and Arafa (2016)	Projects are still assessed by the Iron Triangle, as the project governance is focused on outputs delivery schedule, budget, quality and risks	'Benefits work as drivers for getting project funding only but the project success is still based on the delivery of scope, on cost and time'.
Project life cycle be extended to 5th phase for project outcomes	Zwikael and Smyrk (2012, 2019)	There is a support for the 5th phase but no clarity who will manage the added phase, as project managers are mostly contractors and their contracts are based on funding cycles. Projects must be closed on delivery of the outputs	'There should not be a whole cottage industry of people capturing and reporting benefits, therefore, it should be woven into the performance reporting within the organization in their regular operating reporting'.
PMOs need to adapt their functions to both organizational and strategic contexts.	Hobbs and Aubry (2007)	PMOs in most of the public sector organizations work as post offices for status reporting only	'Most of the PMOs I have seen in the Australian government are post box PMOs'
Each benefit should have a clear owner responsible for monitoring its status, and ensuring that benefits are measured as well	Mossalam and Arafa (2016) Peppard et al (2007)	Senior Responsible Officer (SRO) is a benefits owner by default for all the projects in a program. Reporting benefits depends on the board, there is no mandatory	'You have just been made the SRO because you happen to be responsible for that branch, you do not necessarily know of it'.

		requirement for benefits reporting	'SROs are busy executives and cannot come back after a year to see benefits are realized or not'
Project management and benefits realization, should be integrated under a single governance framework for enhanced project success.	Badewi (2016) Mossalam and Arafa (2016)	The relevance of benefits management framework is limited to benefits identification for a business case	'There isn't a robust benefits framework. We have what is called a benefits management approach or a plan, but it's not been rigorously implemented.' 'We do use the benefit side of the framework, but I don't believe people are taking it seriously'

Discussion:

Business, case, benefits identification, formulation, tracking and measurement:

The effectiveness of business case and its critical role towards the organization has been highlighted by several researchers. Where a business case provides an outline of a project, becomes at basis of project approval, it also requires the identification of expected benefits, though at a high level. In the Australian Public Sector (APS) organizations benefits identification in a business case is a mandatory requirement. An approved business case ultimately becomes a reference point for the evaluation of a project success. Einhorn et al (2020) state that there is a strong evidence of relationship between a business case and project success. But organizations employ business case only prior to starting the project and their findings point out that the business case is seldom used effectively. Einhorn (2020) research which was conducted in South African context is quite recent and it corroborates the findings of our research in the Australian Public Sector, where the business case is important just for the approval of project funding and then project delivery takes the centre stage. Our research highlights that benefits identified in a business case are high level, at times unrealistic and unmeasurable. In the PS, there are two types of projects – Capital Investment Portfolio projects (Internally funded) and New Policy Projects (NPP) also known as external projects. Project identification is internal projects is poor and the NPP are the only projects, where benefits are identified upfront as these come from the government or the minister, where outcomes are already defined and determined. But these benefits are not properly identified and realizable as one research participant said,

> 'The only projects that have clearly defined benefits right up front would be new policy proposals, so the government policy driven benefits, the only problem with those benefits is, they are generally not real benefits, they are more outcomes and they are defined but they do not have the method, for how you would measure it, they do not have baseline values, they are just, we will pluck an outcome, pluck a figure if we think it is so, they are not defined benefits that we can even measure when we get them in because they are generally written by policy fork, who have no project management experience'.

Chih and Zwikael (2015) state that organizations do not have the ability to formulate benefits, which can be measured. Our research echoes the findings of Chih and Zwikael, as benefits are identified as outcomes statements, which are not measurable. Benefits are stated such as 'enhanced customer satisfaction, cohesive Australian society and improving quality'. Our research found that in one case study, benefits are identified by the policy and strategy branches of the organization, with little or no input from the PMO and the end users. In addition to the identification of benefits in the business case, benefits must be aligned to the organizational strategic objectives. Marnewick (2016) states benefits gained from investment in IT projects, are not linked back to organizational strategies and it does not provide insight into organizations, whether the promised benefits have been achieved. Therefore, there can be no certain answer whether the strategic intent has been successfully achieved as a result of investment Young et al (2014). Most of the respondents highlighted that while identifying project benefits, effort is made to align these to organizational goals but the question remains whether it is just a formality or a serious effort, as one of the participants commented that 'organizational goals are such that anything can be aligned to them'. In fact, the major challenge is tracking and measuring the benefits, as soon as the implementation starts, the entire focus is shifted to outputs and the status reporting to the project committees is about milestones, schedule, budget and risks. BM literature puts great emphases on tracking and measuring benefits, but a consistent evidence comes from our research is that benefits tracking, and measuring is not a key concern for either the program managers or the project governance. Allen and Saeed (2018) state that right from the design phase to the entire project life cycle, benefits measuring is of little value. Similar evidence has been highlighted by our research that out of six case study organizations, there is only one organization, where benefits are tracked during the implementation and are measured within 6-12 months after the product/service becomes operationalised. In this case study organization, the benefits realization success rate has been between 30-50 percent (Saeed et al 2019).

Responsibility for Benefits Tracking:

The benefits owner is a key player in effective benefits management and several research participants have criticised the poor role of benefits owner, which is performed by the Senior Responsible Officers (SROs) in the case study organizations. Notionally the SROs are the benefits owners by virtue of being the head of a division or the business area consuming the expected project product/service. So far SROs performance as benefits owner has been lacklustre due to many factors such as their lack of understanding of benefits, their focus on delivery on time and cost and too busy in management matters. However, our research indicates that SRO can be an overall benefits owner during the implementation phase, for being a senior executive and the head of a program board. But once the product/service has been delivered and operationalised, then the Operation Manager should be accountable for benefits measuring and benefits realisation reporting. Benefits realization reporting during first 6 to 18 months in post-delivery period should become a performance KPI of the operation manager. But operational managers claim, they are not provided and funding and resources for benefits measuring and reporting, as operational managers are not skilled in benefits realization. Therefore, a suggestion by Massalam and Arafa (2016) and Peppard et al (2007) that each benefit should have a clear owner to track benefits, is not practically possible in the light of current practices and limited resources and skills for benefits management in organisations. However, we suggest that at the PMO there should be a benefits manager, who would coordinate with the operational manager for benefits realization and reporting.

Massalam and Arafa (2016) also call for the project manager (PM) to track benefits for the entire project life cycle. In the light of industry practices, this suggestion is untenable for several practical reasons. Firstly, in most of the PS organizations, PMs are contractors and hired for project delivery only. In most cases, PMs are engaged after the project approval, where the project benefits have already been identified and formulated, therefore, a PM might find it hard to own such benefits, which may be poorly identified and formulated, and may not make sense or are not measurable and realizable . Secondly, most of the PM's job is the delivery of the product/service within the funding cycle and financial year, therefore, they would not be there after the product delivery and benefits realization would start at least six months after the product has been operationalised. Thirdly, in projects, where there are dependencies across programs, within the organization and beyond, a PM cannot track benefits, therefore, it is more reasonable to expect that benefits should be tracked and managed at the program/portfolio level by the program/portfolio managers, who should be delegated this responsibility by the relevant SROs.

Benefits management at Project, Program or Portfolio levels:

The BM literature has yet to develop a consensus, whether benefits can be effectively managed at the project, program or portfolio levels. Dalcher (2012) states, in the last 20 years, the PM literature has recognised the fact that benefits realization is possible through portfolios. Benefits are identified at the project level and the push for the adoption of portfolio management comes from the demand to measure, deliver and appraise benefits in an organized manner. The Australian government (2012) Assurance Review Process document states that most effective benefits are tangible because these are measurable. For effective benefits management, the document recommends a benefits profile, so that benefits could be collected and managed over the life of a program. The document considers that benefits can be effectively managed at the program level and states that benefits are strategically and dynamically managed throughout the program and beyond.

Our research highlights that in all the case study organizations, BM is carried out at the program level as various projects contribute towards a single program benefit, 'Individual projects themselves rarely deliver a benefit, they are often part of a longer journey, which involves a program delivery, that requires there is a component to be delivered in sequence so that ultimately the program is successful. Further, PMOs in these organizations are not equipped with resources to manage benefits at the project level, as one of the case study organization has 144 projects at a given time running and only three PMOs catering to eight programs. Therefore, at this case study, benefits are identified and mapped at the program level, which provides a program level view for better understanding. Young et al (2017) in their research have studied the possibilities of implementing benefits management at Project, Program and Portfolio Management (P3M) levels to enhance project success. As a part of an action research project, the authors developed a framework to inform business cases for effective benefits management. The authors conclude that benefit management implementation at P3M level is a big ask and it requires change in organizational culture supported by the top management.

PM and BM Integration into a Single Governance Framework:

Badewi (2016) and Mossalam & Arafa (2016) argue for the integration of PM and BM into a single governance framework for enhanced project success. An evidence from our research points towards the efficacy of the suggestion by Badewi, Mossalam and Arafa, as currently in 5/6 case study organisations, PM and BM processes work in isolation of each other. The focus on benefits starts with the business case till the approval of the project. And immediately, after all attention turns to delivery and benefits tracking is carried out sporadically depending on the interest of project board members and later the focus to benefits only returns, if the project is subject to gate reviews. Even there are questions over the effectiveness of gate reviews, as just one week before a scheduled gate review, program managers scramble to collate information on project benefits, which is in most cases, in the form of a spreadsheet. ‘Whenever a gate review or a follow-up date nears then people scramble into action doing ' bits and pieces'. For integrating PM and BM into a single governance framework, organizations need to have a robust and comprehensive BM framework in place. In one case study organization, four research participants gave different information on the use of benefits framework, and some even did not know exactly where the framework is located on the intranet and what is it called. There is only one case study organization that had BM processes woven into all PM processes, which has shown good results in the form of benefits realization success between 30-50 percent.

PMO's Role and Benefits Management:

Darling and Whitty (2016) state, Project Management Office (PMO) is a regularly evolving feature of the PM landscape and the role of the PMO varies in organisations and industries. Hobbs and Aubry (2007) argue that the PMOs need to adapt their functions to both organizational and strategic contexts. Our research found that in most of the case study organizations, PMOs are playing a less desirable role and its primary job has become delivering status reports. Currently, PMOs are playing no to little role in benefits management and in several large organizations PMOs have been contracted out to big four consultancies. In this context, we argue that the PMOs need to play a proactive role in benefits management as the epicentre of benefits management integration into all PM processes. There should be a benefits manager at the PMO to instigate benefits management through training opportunities and coordinate benefits realisation activities with the operational managers, once the project product/service has been operationalised. In our research, we found that in one of the case organizations, the PMO is a hub of BM related processes, where it helps with benefits identification and formulation, defining metrics and benefits tracking. The PMO provides all the technical help, organizes training of project managers and even senior executives and motivation for the integration of benefits management processes into all PM activities. The PMO must evolve further where it is expected to focus on benefits rather than the delivery of widgets.

Conclusion:

This research concurs with the findings of case study research by Allen and Saeed (2018) and Saeed et al (2019) that benefits management practices in the Australian Public Service organisations are patchy and inconsistent and there are a few pockets of excellence, where best practices are followed. There is an early focus on benefits during the development of the business case due to mandatory requirements, but benefits go off the radar as the delivery phase starts. Research participants identified the lack of accountability for benefits, skills and required resources for benefits realization. This research recommends that benefits management should be integrated into all PM processes and BM should be given equal attention assigned to delivery on time, cost and risks in the public sector. This research confirms that there is a gap between the aspiration of researchers and the realities of the practice. This research concludes that there is a general awareness on benefits in the sector, but it does not translate into action perhaps due to the old school thinking, poor understanding of benefits and emphasis on delivery on time and cost. Majority of the research participants expressed optimism for the future of benefits management in the Australian public sector, but they expect, it may take three to five years to achieve maturity with serious efforts to implement on the part of senior executives.

Limitation of This research and Conflict of Interest:

This research was conducted in six organizations of the Australian Public Sector organizations and 45 interviews were conducted and the case study organizations included some of the largest in the public sector implementing hundreds of projects worth billions. However, this research does not claim to be conclusive and recommends a similar research to include the remaining major PS organizations to cover a wider spectrum and build a detailed picture of benefits management in the Australian public sector.

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Management, Surveillance and Quality Assurance; Adding value independent of contract conditions to the post COVID-19 recovery

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Abstract

The construction industry recognised many of its shortcomings from experiences of the global financial crisis (GFC) of 2008 and modified many of its practices. However, in some areas outdated practices still persist. Other industries responded by moving to a value-added or client-centred approach to deliver products and services. The return from current COVID-19 lockdowns across the world presents a new opportunity for the construction industry to reform, with governments seeking to fund large "shovel-ready" infrastructure projects to boost their economies.

"Project 13", is the latest initiative of the Institution of Civil Engineers (ICE) to target a revival of a value-based approach, which should be the focus for ensuring sustainable recovery from the current crisis. The principles of Project 13 are highly transferrable to the construction industry in New Zealand and particularly to public sector infrastructure delivery models. Projects in the infrastructure sector in Auckland have looked to innovation to assist with the demands to accelerate pre-construction phases. Through the deployment of new "digital" technologies in design, schemes have been taken to market in record time. This paper discusses firstly whether acceleration has negatively impacted the traditional measures of project success, i.e. time and out-turn cost and secondly, how

experienced Management Surveillance & Quality Assurance (MSQA) professionals can manage the effects of over-reliance on technology.

The MSQA team, as independent advisors to the parties of the contract can assist to facilitate an ethical approach, through constant questioning of each stage of the design and construction process. Such an approach, particularly in contract administration can ensure that ideas are appropriately scrutinised and also control the potential for 'Group Think'; The forcefulness of influential personalities, or the desire for cohesiveness in a group that may produce a tendency among its members to reach a consensus decision without critical evaluation. Similarly, basic design flaws and construction methodology fundamentals can be overlooked when project resources are stretched and the protection afforded by an additional layer of oversight, to identify design, quality or construction errors, becomes vital.

This paper will investigate how the involvement of a dedicated MSQA team, over successive project phases, can assist to maintain continuity, consistency and comprehensive handover between project participants. Transitioning the same MSQA resource/s into construction supervision and the Engineer's Representative role, can be a key enabler to 'on time' and 'on budget' delivery of projects. Responsiveness to the complex and evolving contractual issues stemming from COVID-19 inactivity and the subsequent recovery efforts, may also be improved. Integrating this overall approach with a value-based procurement model will further strengthen an ability to efficiently address client inputs throughout the lifecycle of projects, irrespective of the chosen delivery model.

The paper will be organised in the following sections:

- Construction clients as drivers of productivity
- NZS3910:2013 and delivering better behaviours from project participants
- Risk allocation and its importance in post COVID-19 recovery efforts in New Zealand
- Digitisation

Keywords: Project 13, Risk Allocation, MSQA advisor, Group Think.

1. Introduction and literature review - Construction clients as drivers of productivity

Research undertaken by the International Monetary Fund (IMF) has shown that increasing investment in infrastructure by a single percentage point of GDP increases the level of output by 0.4% in the same year and by 1.5% four years after (IMF (2014) World Economic Outlook: Legacies, Clouds, Uncertainties). Construction clients are considered as the major steering force for directing construction processes and results (Ryd, 2004). Single clients do not however have the leverage to change the practices of an industry. To change the industry, a national strategy is needed. The British government led transformation plan in the early 2000s resulted most significantly in industry benchmarking and endorsed project & program management processes. A redefined procurement process approach was also introduced in a bid to move from cost-based to value-based, yet resistance to change has persisted. The process in which client needs are translated into requirements, then drawings and specifications, has barely changed in several decades. This process has been succinctly analysed (Forgues, 2005); Potential reasons included poorly integrated delivery mechanisms & supply chains and the bureaucratic framework of professional practice. One conclusion was that incentives to improve have also stagnated, with procurement choices continuing to be based on the lowest bid, with innovation frequently considered as an additional risk and consequently disincentivised. Unfortunately, over fifteen years later, the situation arguably remains relatively unchanged.

The Institution of Civil Engineers (ICE) introduced 'Project 13' as a flagship initiative supported by the 2019 World Economic Forum's; Platform for Shaping the Future of Cities, Infrastructure and Urban Services. Traditionally "separating design from construction and breaking projects down into hundreds of sub-contracts we impede the flow of knowledge from the supply chain to the front end of the project where value is created, adding cost and uncertainty at every step along the way" (Project 13). The key shift required as part of Project 13 thinking, is the adoption of "Enterprise delivery models"; moving away from transactional, cost-driven procurement to the creation of value-driven, collaborative business to business partnerships collectively focused on integrating capabilities to deliver outcomes. Project 13 is an example of several programmes already being implemented internationally to address long-standing issues within the construction industry that will not have gone away in the wake of the COVID-19 pandemic.

Early client adopters of Project 13 are placing a greater emphasis on delivering better outcomes for their customers and accordingly selecting and integrating partners into high-performing teams with the right technical and behavioural capability to deliver. Post COVID-19 recovery efforts are only likely to heighten pressures on client resources and in-house expertise to clearly define desirable asset performance, for infrastructure to ultimately operate as a resilient and interconnected network of roads, railways and utilities. In the White Paper Covid-19 and the new normal for infrastructure systems – next steps, the ICE promotes the use of digitisation programmes to allow a better understanding of assets in use. The UK 'National Digital Twin' concept amongst others, has the potential to enable more effective collection, analysis and use of data to enhance infrastructure performance in the different economic scenarios that may occur following the end of the pandemic.

Multi-skilled MSQA advisors can be strategically engaged to assist to drive projects from conception to delivery more quickly. Accordingly, advisors will be required to be increasingly knowledgeable in construction technology, construction law, conditions of contract, contract administration, project-planning systems and the psychology of negotiations. The demand for such skillsets will become more pronounced where the design of infrastructure conceivably also shifts focus, to respond to expectations for our infrastructure to provide more support for societal resilience and ensure whole-life benefits are spread as widely as possible.

1.1 Procurement and contracting strategies for rapid progression from concept to delivery

During this period of extreme uncertainty, where the risk of change events in normal procurement would cause delays and cost overruns, a blend of procurement and contracting strategies from multiple client groups may be necessary to ensure success. Equally, internal organisational structures and processes do not always allow uncomfortable lessons to be learnt from past mistakes or eliminate the risk of systemic issues going unnoticed. Independent, external resources will need to offer capabilities to not only support the management of client requirements but challenge internal perceptions of value and risk.

Ultimately, procurement and contracting strategies and corresponding Request For Tender (RFT) information & requirements should not be asking for more than what is clearly attainable, substantiated and justifiable, with a clear knowledge of the local market. In New Zealand, this includes recognition of the significant complexities of certain requirements, notably such as 30 year guarantees & performance bonds. External MSQA advisors when engaged pre-construction will need to be particularly investigative and meticulous in developing a clear understanding of changing client needs. To then concisely translate these needs into specifications, Principal's or Minimum Requirements (PR's or MR's), aimed to deliver the best value for money and the best balance of quality and whole life cost to meet end-user requirements. Contract documentation should however be developed with a simultaneous understanding of the contractor's position and view i.e. Why should a contractor enter this contract? What are the inherent project risks and opportunities to strengthen the contractor's position?

1.2. Proactive contract administration and efficient management of change

Best practice would suggest meeting with stakeholders at the outset of any project to arrive at a specific process and then compile a committee to represent both sides of change requests. Irrespective of the stage of the project's lifecycle, in the current environment projects that are perceived to be isolated are unlikely to be tolerated and escape interrogation. The immediate future is likely to see a demand from stakeholders, for wider interconnectivity between infrastructure networks, then maintenance of the interconnected system to deliver long-term sustainability and whole-life benefits.

The client's representative often acts as decision maker, to examine and then approve or deny all requests for scope change that inevitably occur on projects, whilst taking extra care of the important time obligations of the contract. The key to successful change management will always be proportionate to the ability to provide overwhelming supporting documentation to back up the cost and schedule impacts to the project. The Resident Engineer, or often the Engineer's Representative in New Zealand (NZS 3910 Conditions of Contract) is uniquely positioned across the design and project management/ client advisory functions, to cultivate trust between stakeholders and to assimilate informative guidance for the client's project manager/s accordingly.

Stalled project progress at any stage will be particularly toxic to recovery efforts post COVID-19 and after the recognition and acceptance of change requirements, skilled contract administration involves proactively evaluating and processing associated variation concerns promptly. Claims management is however often wrongly seen as adversarial, where instead maintaining cordial relationships will be central to successful outcomes in the current climate. Claims management should consider that it is best to be consistent, to be holistic and to also recognise that there may be a chance to leverage one claim against another. Clarifying requirements early, with a local knowledge of contractor capabilities will also prevent unnecessarily lengthy periods for generation of a variation or extension of time claim. Contractor resource availability will seldom be insufficient to prepare legitimate claims comprehensively, in short order. Delay in submission often results in aggregated time and cost implication claims and the re-litigation of any disruptive affects, that economic recovery efforts can ill-afford. The effect of any intervening or contributory conduct by the client on the time period, and how the process interfaces with any 'early warning' provisions are however important considerations to be evaluated. Relevant considerations do also include whether the knowledge test is objective or subjective, in which case a 'two-stage' notice and resolution process may be appropriate.

1.3. Changing the Basis of Payment and reward

The COVID-19 pandemic has served as a lesson for supply chain resilience and irrespective of the delivery model chosen, a key component of contract documentation in directing a focus on the items of most importance to the customer, is the Basis of Payment (BOP). Payment guidelines can unfairly enforce excessive cashflow constraints on the contractor, by linking payment release solely to progress in the field. Poorly targeted attempts to protect the client' interest through indiscreet payment terms, may result in excessive front-end loading or similar strategies that will not ultimately be conducive to achieving rapid progress and performance on projects. Monitoring and controlling functions/ options for the client and their advisors are critical to ensure early warning of project weaknesses and impending failure. The early submission and approval of contractor's management plans and meaningful progress reports for instance, are fundamental monitoring tools in the best record keeping processes that can be promoted effectively through targeted payment mechanisms.

Going a step further and utilising a similar approach as championed in Project 13, reward for out-performance against baselines or benchmarks may be sought in devising contract documentation/ project requirements, to ultimately include a return for generating value related to outcomes. This back to back commercial arrangement is defined by Project 13 as an important step in creating aligned "Enterprise relationships"; a governance framework that enables effective and collective decision-making, with high levels of transparency and layers of assurance built into the process, ensuring that quality of outcome remains at the core of the enterprise's objectives.

2. NZS3910:2013 and delivering better behaviours from project participants

A universally applicable standard form contract is arguably not realistic. More attention should potentially be placed on ensuring a contract which is up-to date, user-friendly and principles-based. This will successively enable flexible application, or with additional prescriptive requirements on a project specific basis to be applied using Special Conditions of Contract. Most importantly, industry needs a contract that facilitates better behaviour from project participants, particularly in these difficult times.

To further streamline conception to delivery, in the absence of a few currently heavily debated updates to the current NZS 3910 Conditions of Contract, Special Conditions are likely to remain integral to developing robust, project specific RFT documentation for some time. Whilst there is often a need for a legal position on the conditions of contract, and special conditions in some circumstances, lawyers should not be drafting the Principal's Requirements or project specifications. The flexible allocation and opportunity for additional prescriptive requirements must therefore be thoughtfully applied, potentially to:

- Rectify some of the known glitches and shortcomings of the general conditions (for example, certain definitions, time of entry into the contract, rules of assignment, preparation and review of documents);
- Introduce some additional optionality (such as liability caps for contracts, standard exclusion of consequential and economic loss wording, for instance); and
- Reflect current law (such as the Health and Safety at Work Act 2015).

Despite the above requirements, it should not be an unnecessarily difficult or convoluted task to properly understand the contract, with enough time allocated for pre-execution due diligence to be undertaken. It is also important that the contract documents do not contradict each other. There should otherwise not be any reason to present a contract for tender that is clear and transparent in its terms, and which is either consistent across its component parts or which has clearly defined rules for dealing with inconsistency. An MSQA advisor with overlapping knowledge of the design and planning/ consenting of the project, tendering/ tender evaluation phase, is frequently well placed to understand and coordinate all of the contract documents and therefore to later undertake the role of Engineers Representative. When appointed as a representative of an Engineer to the Contract selected from a pool of accredited individuals independent of the designer, this organisational structure ensures impartiality and is arguably both practical and efficient for the client.

3. Risk allocation and its importance in post COVID-19 recovery efforts in New Zealand

Where there is uncertainty, there is risk. Common project risks include weather, ground conditions, labour markets, defective work or materials, inadequate design, incorrect estimating, incorrect programming, natural disasters and not least pandemics such as COVID-19.

Properly understanding the drivers, position and status of each party to the contract is key to achieving fair risk allocation. It is necessary to allocate risk project-by-project, in a realistic, transparent and informed way. The consequences of project risks are invariably realised in contract physical works defects, the time for completion of the contract works and/or the amount payable for the contract works. The current debate is about which party should bear responsibility for identifying, managing and mitigating such risks and which party should bear the consequences of those risks.

When managing the procurement process, transparency in all dealings between the parties to the contract is needed. Appropriately tailored risk allocation, which is properly understood, should be supported by clear, unambiguous obligations within technical specifications, Principal's Requirements or other documentation. Skilled MSQA advice can assist to bridge the gap between design and contract/ construction requirements in developing technical specifications. Requirements around materials testing for instance, should also consider local industry capabilities, recognising that certain requirements are only achievable offshore, and their necessity therefore needs to be carefully scrutinised.

3.1 Transparent contract documentation - tackling a consolidating supply chain

With a consolidating supply chain in the aftermath of COVID-19 inactivity, head contractor's committing to fixed price and tightly programmed contracts, are liable to find their expectations of subcontractor pricing and availability are exceeded due to the excess demand over supply in the industry. Those costs are absorbed by the head contractor, who will see their relatively small margin quickly disappear, leading to solvency issues for themselves and eventually their subcontractors.

Fair risk allocation is integral to supply chain resilience and can arguably only occur after the contracting parties are given the opportunity to discuss the terms and conditions of the contract before they are finalised. This will lead to agreed strategies to mitigate risks and an open conversation about which party is best able to manage the residual risks. In the absence of pre-agreed terms, particularly when acting as an independent expert, the MSQA advisor can add value through the application of nuanced, pragmatic and innovative approaches to risk allocation. It is incumbent on each party to the contract however, to make sure it properly scopes and understands each risk allocated to it. A prudent party to the contract should therefore only accept a risk if it accepts the consequences of that risk on an informed basis. If the commercial drivers of a party are such that it is willing to accept an unwise risk allocation, there should then be no expectation for the Engineer to provide a contract direction that later points at the counterparty. Fairness arguably cannot be enacted in the later stages, through contract administration, as the allocation has already become effective by each party accepting the risk by executing the construction contract and binding themselves to the terms of that contract.

In New Zealand, initiatives such as the 2018 Entwine Report and the industry-led New Zealand Construction Sector Accord, are beginning to garner interest in the market and will potentially drive significant change to observations of a large share of project risk held by the contractor in many current contracts. As is captured by one of the four, key guiding principles of the Construction Sector Accord; 'build trusting relationships', there is clearly a need to devise efficient ways in which risk can be allocated on a basis which is transparent and objectively fair. It should also be recognised that this will not be the resolution of all contractual problems. If a contract is awarded primarily on the basis of price, then this amplifies the potential for greater risk and loss to be passed through the contracting supply chain. There is evidence of the public sector's commitment to move away from lowest price procurement, in line with the Accord principles, which now shows consistency with the latest edition of the Government Procurement Rules.

3.2 Buildability and early contractor involvement

Quickly progressing to delivery phases will assist to unlock the benefits of the public spending programmes necessary to alleviate a dislocated economy and risk of mass unemployment. Provided that permanent works design is pre-completed to a fully compliant level of detail, then arguably a build-only contractor is best placed to assess buildability and construction phasing. Where sufficient opportunity is given to the contractor to review the design and all other relevant information, including conducting site-visits, a well-conceived procurement strategy may facilitate earlier contractor involvement, unlocking benefits to all parties. Locking down the design phase much earlier may allow the manufacturing, assembly, testing and commissioning phases to be compressed and run in parallel, rather than in a long, linear sequence, driving greater efficiencies in how resources are mobilised. It is important however that buildability responsibility is distinguished from Safety in Design (SID) responsibility, the latter of which should rest with the design consultant in a build-only context.

Any allocation of buildability responsibility needs to be pegged to the specifications or the design. An open-ended, immeasurable responsibility to ensure buildability is effectively a quasi-transfer of design risk, as the line between responsibility for design and responsibility for construction is blurred. The nature of buildability is such that, where it becomes an issue, there is often a degree of overlap between the responsibility of the design consultant and the build-only contractor. Where this responsibility turns to liability, it is logical and fair that, to the extent practicable, that liability should be attributed on a proportional basis and any claims framed accordingly.

It is also important that design changes post-tender are properly and completely disclosed to the contractor, with the contractor then being given an appropriate opportunity to review any buildability issues arising out of that change. As an extension of the designers SID procedures and/or handover for construction, a forum or mechanism should be put in place as a component of this process and when facilitated by an experienced practitioner can allow constructability issues to be identified and dealt with. The contractor should be liable for any issues they fail to flag. The principal should be liable to arrange the design to be changed for issues flagged.

Ultimately, an integral part of the Engineer's Representative's role under NZS 3910 Conditions of Contract, is the control of response times and concerns with contractor-submitted requests for information, contractor requests for material-submittal approvals, change management requests, design and constructability requests and procurement approvals. The Contractor however retains a responsibility to ensure compliance with the project specification requirements, including the initial interpretation of supplier's submittals/ proposals/ testing, arguably applying a buildability perspective. Requests for information are traditionally routed through the design team for responses & feedback and should be closely examined by the Engineers Representative prior to transmitting back to the contractor. Inevitably design team changes will occur between design, tender and implementation phases of projects, requiring an overarching/ overlapping involvement of a dedicated MSQA team resource to maintain continuity and handover between phases. This will enable appropriate challenge of contractor requests and the designer's responses, accordingly, reflecting on the final contract conditions, contractor's tender, the developed design intent and overall client requirements.

4 Digitisation

The ICE civil engineering blog; Why civil engineers should feel a 'chronic uneasiness' about their work details how rapid delivery aspirations and excessive digitisation combined and resulted in the failure of the Florida International University Bridge in the USA. Investigations revealed that no action was taken despite the visual evidence of severe cracking, because the computer model was not predicting a failure. An argument can be made for an approaching industry wide over-reliance on computer-generated solutions. There similarly remains the danger of projects becoming a victim of "Group Think" mentality, that may stem from a possible over-reliance on technology; Where influential personalities within the project team are often able to force consensus for the benefit of progress or protecting particular interests, despite misgivings and technical expertise that advises against certain actions. The team moves forward as a group in the worst-case scenario, with underlying, basic design flaws and a lack of oversight by every party that had responsibility to identify errors. Particularly in MSQA advisory roles, professionals with the right ethical approach are needed to form collaborative teams, who are constantly questioning the trajectory of the project to avoid getting sucked into 'group think'.

Building Information Modelling (BIM) is now widely used across the industry but with varying degrees of success and frequently not consistently throughout project phases. Unfortunately, BIM is also often only applied in a collection of projects without recognising the need for infrastructure to operate as a system of systems. 3D modelling undoubtedly has benefits in simplifying the complex interrelationship between engineering disciplines through visualisation. The extension of such techniques into construction supervision systems will also therefore extend benefits to the construction phase, by allowing inspectors to intuitively understand the design intent and interim construction staging before construction commences. This process will ultimately enable more comprehensive and targeted inspections, relieving concerns of potential omission or negligence and alleviating the use of standard documents without project-specific review and bespoke inputs.

Conclusion and next steps

The establishment of a pipeline of anticipated government infrastructure projects by the New Zealand - Infrastructure Transaction Unit is a step in the right direction. It could help provide those in the industry with the confidence needed to invest, to drive recovery from the disruptions caused by the COVID-19 lockdowns. The pipeline needs to be further developed and its success is contingent on public sector agencies adhering to it (irrespective of short-term electoral cycles). Without that, it is unrealistic to expect industry to rely on pipeline commitments and to invest based on them or to seek to enable greater use of off-site manufacture and progress developments to enhance industry productivity.

The rapid progression of projects from conception to delivery phases will be key to unlock the potential that large public spending programmes have for economic relief and for the prevention of mass unemployment. Many of the discussion points in this paper promote the uptake of key principles from pre-established industry initiatives such as the Institution of Civil Engineers' Project 13. These initiatives were devised to address long-standing issues in the construction industry that have only become more relevant in ensuring sustainable recovery from the COVID-19 pandemic.

During this period of extreme uncertainty, preparing a project and contract for tender that is clear and transparent in its terms, and which is either consistent across its component parts or which has clearly defined rules for dealing with inconsistency, is considered a fundamental prerequisite for success. Key steps to achieving this, fast-tracking projects for delivery and subsequently safeguarding the interests of all parties to the contract, are concluded as follows:

- It is incumbent on those practitioners engaged in the development of contract documentation to take care to intimately understand and articulate client requirements through the Request for Tender project documentation. The target should be presentation of a package of information for delivery of the best value for money, and the best balance of quality and whole of life cost to meet the end user's requirements. Effective 'non-price attribute' evaluation of tenderers can then occur to ensure that contracts and supply arrangements are put in place with organisations who can demonstrate their commitment – either by direct investment or collaboration with specialists, to strive for the real objectives of the client body.
- Requests for change throughout any stage of the project are inevitable, but potentially major roadblocks for efficient performance and programme delivery. Change should be proactively managed with early decision making. This approach should subsequently be applied throughout all successive phases of the contract administration of variation requests, accordingly, concisely delivering and evaluating overwhelming supporting documentation to back up the cost and schedule impacts to the project
- Applying a nuanced, pragmatic and innovative approach to risk allocation is integral from the outset and to ensuring supply chain resilience. Irrespective of the delivery model chosen, it is necessary to allocate risk project-by-project in a realistic, transparent and informed way. This approach should be consistently reflected throughout all key contract documents, including the basis of payment, liquidated damages and Special Conditions.
- Using established technologies can address weak productivity growth in delivering projects and programmes within the construction industry. Broadly, as outlined in the ICE White Paper Covid-19 and the new normal for infrastructure systems – next steps; a

structured approach to managing data about infrastructure networks as a whole, will allow new investments to be assessed in the context of how that new asset or system fits in with the existing infrastructure system and what the interdependencies and cross-sector impacts are. More specifically, 3D modelling and the use of Building Information Modelling (BIM) technology to develop a virtual library of high value products for use across a range of future projects and programmes, will be key enablers for efficiency gains. Ownership of buildability responsibility and extending the use of BIM from simply laying out project design, into construction supervision, will also improve processes, reduce errors and eliminate disputes.

Further specific benefits can be realised in engaging skilled, independent Management Surveillance & Quality Assurance (MSQA) advice in the industry's post-COVID-19 recovery phase. Irrespective of the contract conditions, the potential added value of such assistance is considered to be wide-ranging and is summarised as follows:

- Devising appropriately tailored risk allocation, which is properly understood and supported by clear, unambiguous obligations within technical specifications, Principal's Requirements or other contract documentation.
- Bridging the gap between design and contract/ construction requirements in developing technical specifications.
- Inevitable team changes between design, tender and implementation phases of projects may be supported by the overarching/ overlapping involvement of a dedicated MSQA team resource, to maintain continuity and handover between phases. This will enable appropriate challenge of contractor requests and the designer's responses, accordingly, reflecting on the final contract conditions, contractor's tender, the developed design intent and the overall client requirements.
- Supporting the management of client requirements whilst challenging internal perceptions of value and risk.
- Mitigating poorly targeted attempts to protect the client' interest through indiscreet payment terms. Consequences may otherwise be excessive front-end loading or similar strategies that will not ultimately be conducive to achieving the rapid progress and performance demands of recovery strategies.

Particularly in MSQA advisory roles, professionals with the right ethical approach will be needed to form collaborative teams, who are constantly questioning the trajectory of the project to avoid getting sucked into a 'Group Think', in the interests of driving projects from conception to delivery more quickly.

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A Case Study for Recovery Scheduling in Transportation

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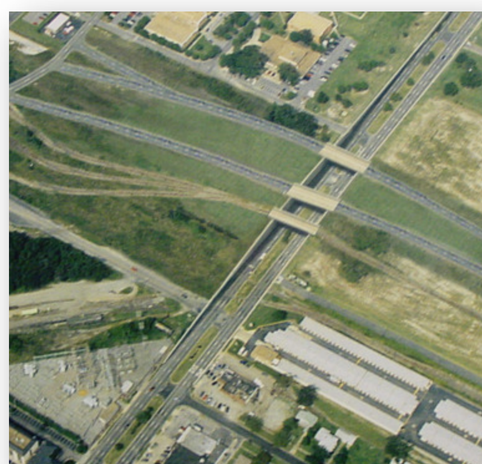
Introduction

When transportation projects fall behind, it can be very difficult to regain the lost time, and even harder without increased costs. This paper walks the reader through the resolution of a schedule recovery need for a transportation project which suffered significant production losses by analyzing the project, identifying specific opportunities for acceleration, hosting a recovery workshop, and implementing the solutions. This structured and cost-effective case study for recovery uses an ongoing project for which the authors provided Project Controls, specifically Schedule Review, support, and demonstrates the technical scheduling process used to recover the time.

Background

Project Description

The approximately $40M Hampton Boulevard project depresses the grade of a four-lane thoroughfare leading to Naval Station Norfolk in order to change grade crossings to bridges and remove traffic interruptions. The Project also includes constructing two bridges, one each for rail and traffic overpasses. The work was divided into four phases. Phase 1 consisted of Building the detour road at the current grade around the primary construction area rerouting all four lanes to the north side while maintaining access for side streets. Phase 2 consisted of demolishing existing Hampton Boulevard, relocating rail access to the terminal, driving sheet piles, excavating to the new grade for approximately 60% of the project, driving piles, pouring slabs, and building bridges over the excavated area. Phase 3 consisted of driving sheet piles, excavating the remaining 40% of the Project, driving piles, pouring slabs and tying into Phase 2 completed work. Phase 4 is the traffic shift to the newly built roadway, demolishing the detour road, and landscaping. The Original Duration for the Project was 1223 calendar days or just over 40 months.



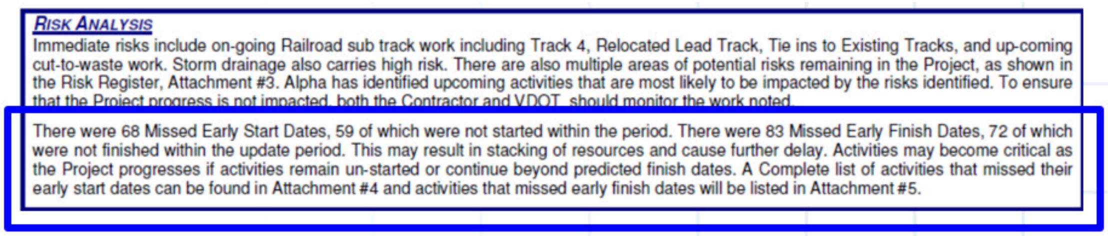
The purpose of this project is to separate the rail traffic servicing the adjacent Norfolk International Terminal (NIT) from the heavy automobile traffic. The current alignment also poses a problem for the Navy. If the Navy recalls all personnel but doesn't get cooperation from the Terminal on the rail traffic, it could negatively affect operational readiness.

Schedule Model

The Baseline Schedule was a 672-activity Critical Path Method schedule ("CPM") that was reasonable and appropriate. The scheduling environment on this job was one of cordial cooperation. We were able to discuss issues with the contractor and resolve disagreements relatively easily.

Statement of Recovery Need

The problem arose when the completion date slipped and the contractor felt that he had exhausted all logical mitigations he could make and still have faith in the schedule as a reasonable and achievable plan to complete the Project. The DOT requested that the contractor provide a recovery schedule. The Contractor wanted relief from liquidated damages; however, the Owner decided that releasing the Contractor from liquidated damages was not in The DOT's best interest. As the consultant to the DOT providing schedule review services, we proposed a schedule recovery workshop to address the production slippage.



RISK ANALYSIS

Immediate risks include on-going Railroad sub track work including Track 4, Relocated Lead Track, Tie ins to Existing Tracks, and up-coming cut-to-waste work. Storm drainage also carries high risk. There are also multiple areas of potential risks remaining in the Project, as shown in the Risk Register, Attachment #3. Alpha has identified upcoming activities that are most likely to be impacted by the risks identified. To ensure that the Project progress is not impacted, both the Contractor and VDOT should monitor the work noted.

There were 68 Missed Early Start Dates, 59 of which were not started within the period. There were 83 Missed Early Finish Dates, 72 of which were not finished within the update period. This may result in stacking of resources and cause further delay. Activities may become critical as the Project progresses if activities remain un-started or continue beyond predicted finish dates. A Complete list of activities that missed their early start dates can be found in Attachment #4 and activities that missed early finish dates will be listed in Attachment #5.

Schedule Status

The schedule at this point had gone through six months of a "slip and recover pattern" where the Contractor updated the schedule, noticed the slip and mitigated that slip through logic changes. In most cases, the logic changes were carefully thought out and implemented, but eventually reasonable changes did not provide the recovery needed, and actions were taken in an optimistic manner anticipating higher production and increased crew resources.

The Contractor's management team had reviewed the schedule and concluded that there were no more cuts to be made, or durations to be trimmed, and no other options than to ask for relief.

Goal

The goal of any Schedule Recovery Workshop is to come together to brainstorm ideas for sequencing, opportunities for additional resources to shorten durations, site conditions or changes that would enable a time savings.

Recovery Workshop

Preparation

In preparation for the Recovery Workshop, all of the participants should prepare a bulleted list of suggestions for discussion with the group. Sending the list ahead of time allows the Contractor time to evaluate these ideas which helps the Recovery Workshop proceed without becoming an interrogation of the Contractor to which there are no answers at this time.

- Cure for 7 days is a VDOT standard, but on the schedule it shows cure driving the CP as if no other work is ongoing in adjacent areas. Is this an accurate model of the real world?
  - What about the use of Curing Compound to maintain the cure after the forms are removed? Does this impede adjacent work?
- What is the constraint to driving the sheet piling on both east and west sides concurrently?
- Two tie back crews running concurrently on both sides would help speed the excavation.
- What about two Cranes for pile driving both sides of the excavation concurrently?
- Fabricating Piles will be from Mid December to Mid Jan, which may be slow months for the fabricator. What about verifying the expected capacity availability of the fab plant at that time? If they can commit to greater production rates, it would help.
- Activity #3AAR0050 "CONCRETE MEDIAN - 15+80 TO 11+88 - HAMPTON BOULEVARD" is a 19 Work Day activity that may need to be broken up to accurately reflect the planned sequence of construction. This further breakdown of the activity could allow staged successors, picking up time.
- Is there a reason for not paving both sides North and South bound concurrently? If paving is driven by physical logic rather than resource logic (assuming one pile driving rig),
- Activity #3AARN040 "PAVE NB 15+60 TO 11+60 - HAMPTON BOULEVARD" is linked in as a successor to the Sidewalks being complete. It appears that this sidewalk is poured between C&G, so paving should be able to start once the C&G has cured sufficiently.

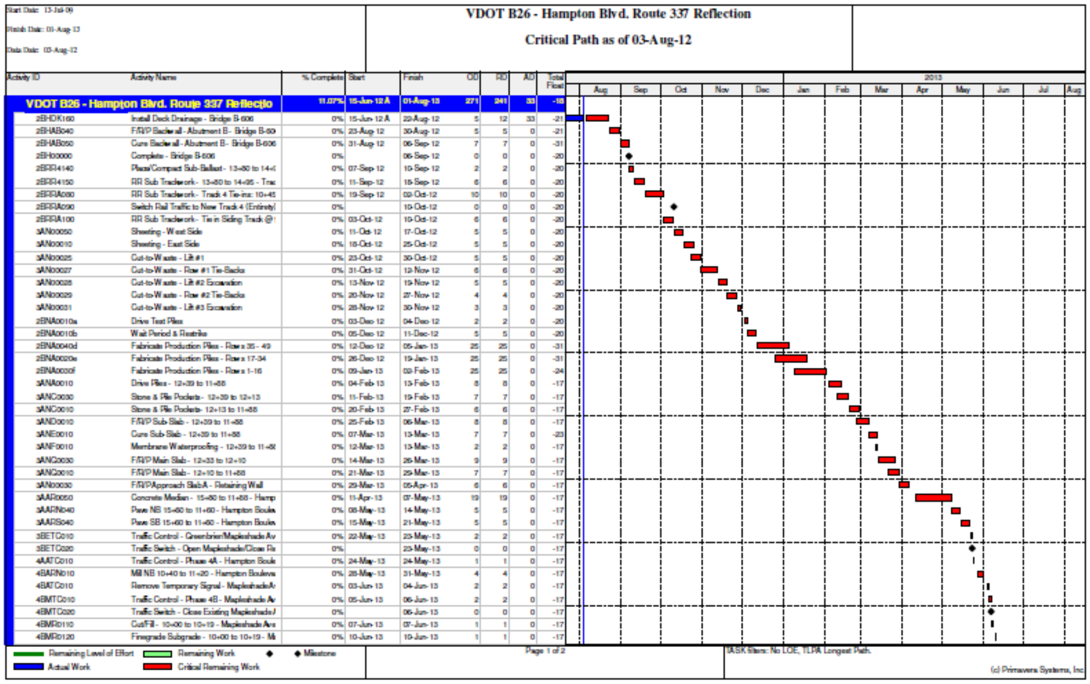
Brainstorming

Brainstorming is critical to allow all participants the chance to contribute and comment. This is a vital part of obtaining the buy-in of all of the participants.

Most effective recovery efforts involve revisions to both the Longest Path and the Near Critical work that becomes the Longest Path as changes to the previous Longest Path shortens the work duration.

Preliminary Analysis

In this case, the authors' brainstorming was facilitated by using the most current updated schedule, filtered to show only the Longest Path, Critical and Near-Critical paths up to the value of the time needed to recovery, which was approximately 45 calendar days. The filtering was done by defining the Critical Path to include all activities up to 45 days of Total Float, inclusive. These are the activities that control project completion for the recovery time frame and all of these activities may need recovery in order to meet the goal.



This approach is much more efficient than starting with just the Longest or Critical Path, which is the typical approach by most schedulers. Starting with the longest pole in the tent, the Critical Path, simply solves the apparent problem, but as the Critical Path is recovered, those activities slip off the path and some other secondary Critical Path takes over, requiring another recovery effort.

Once the schedule is filtered to the recovery duration, the next step relates to choosing the best opportunities for recovery. In recovery efforts, there are generally two choices; fast-tracking or compressing. Fast-tracking is changing the sequencing and logic so as to create more concurrent work, potentially changing one Longest Path into two shorter Longest Paths of the work that does not depend on the original predecessors. Compressing generally requires shortening of durations by adjusting productivity rates with increased efficiencies or increased crews.

The recovery brainstorming should look at both options. Fast-tracking the project is less likely to increase costs than compressing so that is the obvious preferred approach.

Fast-tracking opportunities should start with review of the Critical Paths to see where there might be soft logic driving the Critical Path. Soft logic, which could be resource-driven or simply preference-driven, can often be revised to allow more parallel or concurrent work. Some of the opportunities for fast-tracking are recognized by the longer durations; leading to opportunities to subdivide large scope activities into multiple activities which might be able to progress concurrently.

The approach to prioritize this effort starts with changing the sorting of the schedule from Early Dates to Original Durations, with the larger ODs listed first as those are the best opportunities.

Activity ID	Activity Name	% Complete	Start	Finish	OD	RD	AD	Total Float
VDOT B26 - Hampton Blvd. Route 337 Reflectio		75.41%	13-Jul-09 A	01-Aug-13	980	241	739	-18
GC-11	Survey	70.39%	13-Jul-09 A	01-Aug-13	814	241	750	-18
GC-1	Trailer	70.06%	13-Jul-09 A	01-Aug-13	805	241	750	-18
2BNA0030f	Fabricate Production Piles - Rows 1-16	0%	09-Jan-13	02-Feb-13	25	25	0	-24
2BNA0020e	Fabricate Production Piles - Rows 17-34	0%	26-Dec-12	19-Jan-13	25	25	0	-31
2BNA0040d	Fabricate Production Piles - Rows 35 - 49	0%	12-Dec-12	05-Jan-13	25	25	0	-31
3AAR0050	Concrete Median - 15+80 to 11+88 - Hamp	0%	11-Apr-13	07-May-13	19	19	0	-17
4BBR0010	Demo Hampton Blvd. Detour Road	0%	18-Jun-13	01-Jul-13	10	10	0	-17
2BRRA080	RR Sub Trackwork - Track 4 Tie-ins: 10+45	0%	19-Sep-12	02-Oct-12	10	10	0	-20
3ANG0030	F/R/P Main Slab - 12+33 to 12+10	0%	14-Mar-13	26-Mar-13	9	9	0	-17
3AND0010	F/R/P Sub-Slab - 12+39 to 11+88	0%	25-Feb-13	06-Mar-13	8	8	0	-17
3ANA0010	Drive Piles - 12+39 to 11+88	0%	04-Feb-13	13-Feb-13	8	8	0	-17
3ANC0030	Stone & Pile Pockets - 12+39 to 12+13	0%	11-Feb-13	19-Feb-13	7	7	0	-17
3ANG0010	F/R/P Main Slab - 12+10 to 11+88	0%	21-Mar-13	29-Mar-13	7	7	0	-17
3ANE0010	Cure Sub-Slab - 12+39 to 11+88	0%	07-Mar-13	13-Mar-13	7	7	0	-23
2AUR0070	Storm 3-5,3-3,3-2,3-1	0%	08-Jul-13	16-Jul-13	7	7	0	-17
2BHAB050	Cure Backwall - Abutment B - Bridge B-606	0%	31-Aug-12	06-Sep-12	7	7	0	-31
3ANC0010	Stone & Pile Pockets- 12+13 to 11+88	0%	20-Feb-13	27-Feb-13	6	6	0	-17
3AN00030	F/R/P Approach Slab A - Retaining Wall	0%	29-Mar-13	05-Apr-13	6	6	0	-17
3AN00027	Cut-to-Waste - Row #1 Tie-Backs	0%	31-Oct-12	12-Nov-12	6	6	0	-20
2BRRA100	RR Sub Trackwork - Tie in Siding Track @ !	0%	03-Oct-12	10-Oct-12	6	6	0	-20
2BRR4150	RR Sub Trackwork - 13+80 to 14+95 - Trac	0%	11-Sep-12	18-Sep-12	6	6	0	-20
3AARS040	Pave SB 15+60 to 11+60 - Hampton Boulev	0%	15-May-13	21-May-13	5	5	0	-17
3AARN040	Pave NB 15+60 to 11+60 - Hampton Boulev	0%	08-May-13	14-May-13	5	5	0	-17
2BNA0010b	Wait Period & Restrike	0%	05-Dec-12	11-Dec-12	5	5	0	-20
3AN00028	Cut-to-Waste - Lift #2 Excavation	0%	13-Nov-12	19-Nov-12	5	5	0	-20

This project had an activity for concrete curb and gutter (C&G), with monolithic sidewalk, that separated the lane directions, with a single large duration of 18 WD. After review of the plans, it appeared that the C&G activity could be divided into two activities to allow two crews and work on both directions of traffic to occur at the same time.

All options should remain on the table, and this means that some of the suggestions will turn out not to be viable once analysis is done. An example of this was the opportunity identified in the Activity names "Fabricate Production Piles", which appeared to offer acceleration options from either faster fabrication or quicker delivery.

We also reviewed predecessors to the fabrication activities to examine other opportunities with starting earlier. The schedule showed three groups of production piles to be fabricated, totalling 25 work-days, which is five weeks, and even with the overlap between groups, the entire process was shown to require 6 weeks.

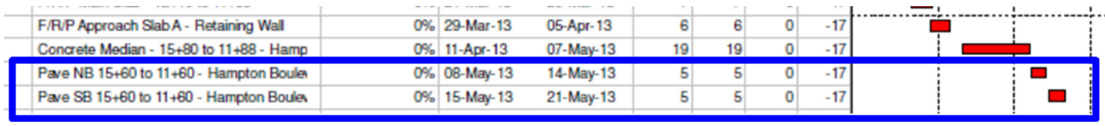
Drive Test Piles	0%	03-Dec-12	04-Dec-12	2
Wait Period & Restrike	0%	05-Dec-12	11-Dec-12	5
Fabricate Production Piles - Rows 35 - 49	0%	12-Dec-12	05-Jan-13	25
Fabricate Production Piles - Rows 17-34	0%	26-Dec-12	19-Jan-13	25
Fabricate Production Piles - Rows 1-16	0%	09-Jan-13	02-Feb-13	25
Drive Piles - 12+39 to 11+88	0%	04-Feb-13	13-Feb-13	8
Stone & Pile Pockets - 12+39 to 12+13	0%	11-Feb-13	19-Feb-13	7

This opportunity proved not to offer any good options to reduce time, even though it was high on our list.

Other opportunities for recovery included identification of dead time in the longer sequences, such as the Activity names, "Concrete Median". This activity was scheduled for the full median installation, requiring 19 work-days.

F/R/P Approach Slab A - Retaining Wall	0%	29-Mar-13	05-Apr-13	6	6	0	-17
Concrete Median - 15+80 to 11+88 - Hamp	0%	11-Apr-13	07-May-13	19	19	0	-17
Pave NB 15+60 to 11+60 - Hampton Boulev	0%	08-May-13	14-May-13	5	5	0	-17
Pave SB 15+60 to 11+60 - Hampton Boulev	0%	15-May-13	21-May-13	5	5	0	-17

The Northbound lane of paving in the depressed area was scheduled to start only after the complete median was installed even though there was work on both the North- and Southbound sides. By starting the paving on the NB side immediately after concrete median was complete on the NB side only, the schedule gained time. This shows how the brainstorming builds on other ideas.

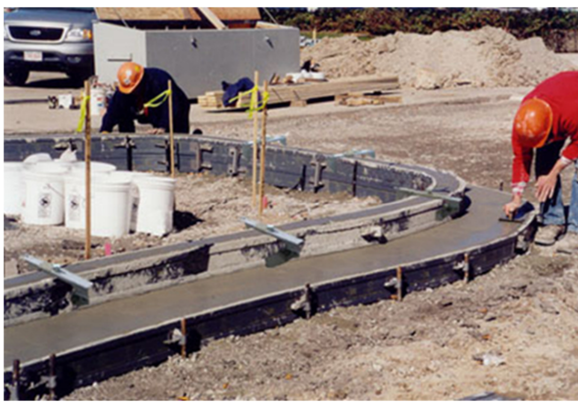


F/R/P Approach Slab A - Retaining Wall	0%	29-Mar-13	05-Apr-13	6	6	0	-17
Concrete Median - 15+80 to 11+88 - Hamp	0%	11-Apr-13	07-May-13	19	19	0	-17
Pave NB 15+60 to 11+60 - Hampton Boule	0%	08-May-13	14-May-13	5	5	0	-17
Pave SB 15+60 to 11+60 - Hampton Boule	0%	15-May-13	21-May-13	5	5	0	-17

After review of the fast-tracking opportunities, the next step is to examine compressing the schedule. This requires a review of the quantities and production rates that were used to estimate the durations of activities.

The large duration sort of the Critical and Near-Critical Path filters is a good layout to use to examine the compression opportunities as well. The small durations will likely not yield much savings, whereas the large durations could generate significant savings for the recovery effort.

In this project, the authors reviewed the production rates of the work to see if there were any good opportunities to improve productivity, and discovered that the C&G production rates were based on hand forming and pouring the concrete. If the Contractor could bring in a curb machine instead of hand forming the C&G, the production rate could be increased dramatically.



The brainstorming session continues in this way, addressing all ideas and examining the schedule in as many innovative ways as possible. But the success is based on a technical review of the schedule – remember that the schedule is the technical model of the project plan; if the model is accurate, it will help expose efficiencies in the plan that are not being taken into account.

Facilitating Workshop

Opening Statement

The objective at this meeting was to discuss proposed feasible ideas with all sides to determine what changes could be adopted that would result in an achievable recovery schedule. Use of a brainstorming meeting was originally conceived by the author Carson of this paper in a Recommended Practice also authored by him in 2007[1].

[1] Recommended Practice No. 54R-07, "Recovery Scheduling", Association for the Advancement of Cost Engineering (AACE) International, Morgantown, WV, 2007

Discuss Ideas

The result of this meeting is a recovery schedule, but the schedule remains the Contractor's means and methods and sole responsibility.

The beauty of the Recovery Workshop is that different people are looking at the schedule. Individuals perceive the same item slightly differently. This allows for healthy discussion which leads to productive ideas.

Identify Acceptable Targets

Once these ideas have been deemed technically feasible, practical, and discussed with the group, then these specific concepts become the acceptable targets for mitigating the delays in the Project schedule. These targets need to be modelled in the schedule. This list of targets is taken by the Contractor who then needs to perform an analysis to determine which, if any, may be applied to the CPM to produce the Recovery Schedule.

Output/Results

Recovery Analysis

Recovery options were analyzed individually and cumulatively. The cumulative analysis is important as the changing Critical Path will make some ideas less feasible or less attractive as the reductions in Critical Path lengths moves the Critical Path to other activities and sequences.

The workshop yielded a list of proposed schedule changes that were acceptable to all parties and saved the Project 38 calendar days. These changes that were ultimately adopted added no cost to the Project and mostly changed the sequencing of work. Paving, sidewalks, curb and gutter were originally scheduled to be completed at the end of Phase 3 for the entire length of the Project. The proposal to break out the work for Phase 2 and complete this early when the area is complete and available for work, rather than waiting for the completion of Phase 3 saved the majority of the time. Other small changes accumulated to the remaining time savings.

Recovery Plan Acceptance

The Recovery plan must be acceptable to all parties. Both Parties must analyze the Recovery Schedule for feasibility, resources, compliance with the specifications, and the Owner in particular should review to confirm that the recovery effort does not place new burdens or constraints on his in-house and consultant resources.

Implementation of Recovery Plan

Once the Recovery Schedule is approved, it becomes the schedule of record on which Earned Value Management, Earned Schedule Analysis, completion predictions, delay analysis, and Payment Applications will be based. The Recovery Schedule is the new plan to complete the remaining work within the Contract time frame. Future schedule updates will use the Recovery Schedule as the benchmark schedule to create the Updates. The Recovery Schedule or its updates will be used as a basis for any required analysis of potential needs for extensions of time with TIAs for delay events that may impact the job.

It is vital to recognize that recovery scheduling efforts are always more successful when they require the efforts to start immediately rather than counting on a future effort. The project must be turned around to gain recovery, and a small part of the problem is the motivational losses that have occurred due to the recognition of delay. When the project team sees recovery starting and proceeding right away, it helps motivate the entire team to perform at a higher level.

Recovery plans designed to occur in the future can also fail when the project continues to lag or other unforeseen conditions occur to retard performance. The sooner the recovery effort starts, the more likely it will be successful.

Summary/Conclusion

Every project at some point in the project life-cycle is likely to need recovery efforts, and following a structured approach will improve the opportunities to recover as well as reduce the time and effort to develop the recovery plan. Recovery Workshops provide opportunities for partnering, with the Owner and Consultant/CM participating to help the Contractor meet their goals and commitments.

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The Origins of Schedule Management.

The concepts used in planning, allocating, visualizing and managing time in a project have very deep roots.

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Abstract

Getting the right people in the right place at the right time has always been a major organizational challenge. In ancient times this process seems to have been accomplished based on the scheme of arrangements being contained in the leader’s mind and instructions communicated verbally. Modern approaches to solving the twin challenges of first thinking through the ‘plan’ and then communicating the plan to the people who need to do ‘the right work, at the right time, in the right place’ use sophisticated graphics, charts, diagrams, and computations. This paper traces the development of the concepts most project managers take for granted including bar charts and critical path schedules from their origins (which are far earlier than most people think) through to

the modern day. The first section of the paper looks at the development of concepts that allow the visualization of time and other data. The second looks at the shift from static representations to dynamic modelling through the emergence of computers, dynamic calculations and integrated data from the 1950s to the present time.

Keywords: Time management, scheduling, CPM, PERT, Gantt, Critical Path, bar chart.

1 Introduction to the concept of visualising time in projects

The three elements of the 'iron triangle' of project management may be simplistic and outdated but still serve a useful function for understanding the essence of a project and the management needed to achieve its objectives. Project management in its modern form, and its equivalent in earlier times required the responsible manager to:

- Understand what had to be achieved to satisfy the client (in modern terms scope, design, quality, reliability, maintainability, function and form; these are all interrelated).
- Understand how much money was available to fund the works and how flexible this constraint was.
- Understand how to accomplish the works and the time available to complete the 'project'. Then and now this involves a complex set of functions to make sure the right people and materials are available in the right place at the right time to allow the work of the project to progress smoothly.

1.1 Understanding shape and form

The perennial challenge facing every 'project manager' from antiquity through to the modern day is ensuring that they understand enough of the project client's requirements to be comfortable they were working on the right thing. The next step is to break down the overall project into multiple smaller challenges and to ensure each work team and each worker understands what they have to achieve. The techniques used to develop this understanding and convey the information seem to have remained fairly constant for millennia.

1.1.1 Narrative, stories and discussion

Talking through the client's objectives and requirements using effective questions and 'active listening' has always been central to building understanding. The only problem with dialogue is recording the agreement and actually knowing both sides of the discussion have the identical mental picture of what the finished project will look like. This is less of a problem in relatively slow changing environments that employ well-understood techniques and processes, and where the 'product' is tangible (eg, a pyramid, cathedral or ship). When something totally new is being discussed problems of understanding may arise, but this does not stop the creation of 'use cases' being a central design element in most software projects.

1.1.2 Models
Simple models of all, or part, of a building or project help the explanation process by providing a central focus for the discussion. There are suggestions that the builders of the pyramids used models to demonstrate proposals. Edwards (1993) describes two pyramid models carved from limestone: one of a stepped pyramid, the other of a smooth sided pyramid (the 'new idea').

By the 17th century models were in regular use. The National Maritime Museum in London has a 1:48 contemporary skeleton model of the St Michael, a 98-gun warship built by John Tippetts and launched at Portsmouth Royal Dockyard in 1669. This is possibly the oldest model that can be connected to a specific vessel (Ball, 2016). By 1716 the British Navy Board had ordered that all ship draughts (proposals) for new vessels and repairs to be accompanied by a scale model (RMG, 2018).

The reconstruction of St Paul's Cathedral after the Great Fire of 1666 similarly used a model at 1:25 scale to demonstrate the design intent of the architect Sir Christopher Wren. The model was built in 1673/74 by William Cleere and was designed to be viewed at 'eye level' to give a true impression of the interior (Corporation of St Pauls, 2018). Fast forward 400 years and the same techniques are used in the virtual world of today's design.

1.1.3 Formalised designs
The use of drawings and sketches also seems to have been common practice from the earliest times. The Ancient Egyptians produced plans and sketches of buildings and referenced design texts that held standard formula derived from trial and error such as the 'Book of Foundations of Temples' (Kozak-Holland, 2011, p71). By the early 15th century the concept of perspective derived from architectural plans had been defined by Filippo Brunelleschi (Dauben, 2018).

The modern concept of engineering design was formalised in the 18th century by French mathematician Gaspard Monge. He published Géométrie descriptive (1798), which is regarded as the first book to formalise orthographic projection and descriptive geometry. Orthographic projection is a way of accurately representing three-dimensional objects using two dimensional drawings, usually a top view (plan), a front view and one side view (front and side elevations). In each drawing, the object is viewed along parallel lines that are perpendicular to the plane of the drawing allowing dimensions to be measured accurately from the drawing. This work was used by the École Polytechnique which had been established in 1794 to train all candidates for specialist civil and military engineering roles in the French republic.

The concepts published by Monge facilitated the growth and development of the drafting profession which was linked to the need to manufacture the interchangeable parts required to build and service the machinery of the industrial revolution. This trend was reinforced by the introduction of the blueprinting process, and the economy offered by creating a set of drawings that in most cases made the building of a working model unnecessary.

1.2 Understanding cost and budget
Understanding and controlling the cost of proposed projects seems to be as old as the concept of paid labour. However, the application of cost estimating and controls has always been patchy. Some projects such as the construction of Cathedrals in the Middle-Ages seem to have been developed using a 'keep-going-until-its-finished' approach that in some cases took more than 100 years to see the work completed. Other projects seem to have been far more controlled.

In 2500BCE, the workers on Pharaoh Khufu's Great Pyramid at Giza were paid in kind (grain, beer, etc.). With thousands of people on a site in the middle of the desert, calculating the quantities needed to be brought to site each season and the logistics of payment required a very sophisticated system. This degree of sophistication appears to have been well within the capabilities of the Egyptian state's bureaucracy (Smith, 2004).

The ability to control costs may have been applied inconsistently through the millennia but there are many examples from history showing that very precise controls were possible. For example, the available documentation for the construction and operation of the Crystal Palace in London for the Great Exhibition of 1851, contained in five reports of the Royal Commissioners, shows a high degree of control. In their second report, the Commissioners predicted a final profit of £173,000. In their fifth and final report the profit was declared at £186,436. 18s. 6d. The project was built in a remarkably short timeframe and the difficulties of taking an incomplete design through to a completed building open to the public in just 8.5 months were recognised by the Commissioners and additional compensation was paid to the builder. However, nowhere in the records are any indications of how this work was Organized and managed to achieve the level of control evidenced by the cost reports (Weaver, 2014 [2]).

1.3 Understanding and managing the available time

The concept of binding contracts with defined scope and costs go back to the Roman era and perhaps earlier. Even without the incentive of a contract the ability to estimate and manage costs requires the ability to:

1. Estimate the amount of work involved in a project;
2. Determine the resources needed to accomplish the work in the available time;
3. Organize the workers to accomplish the work in the allowed time;
4. Deal with emerging issues to maintain the agreed cost and time.

These four elements had to be implemented and used effectively to achieve the successful outcomes detailed above, and similar successes across the millennia. We know from records dating back 6000 years that the mathematics need to estimate physical quantities and work content were available to both the Sumerians and Egyptians (Mansfield, 2017). The historical records also show that the work was managed and controlled. What's missing is any indication of the techniques used to implement this management. Was it purely intuition and learned experience? Or were there processes applied to assist in achieving the desired outcomes? The balance of this paper will look at what is currently known about the emergence of specific processes and techniques to help manage project work.

2 The development of the concepts that allow the visualization of time

Getting the people who are needed to do the right work, into the right place, at the right time, with all necessary tools, equipment and other resources needs a plan! Then the plan has to be communicated to the right people in sufficient time for them to be able to implement it.

It is feasible for the planning to be undertaken in a controlling manager's mind based on intuition and learned experience. It is also feasible that the necessary information could be communicated to work teams in a series of one-on-one conversations supported by ad hoc aids such as freehand sketches drawn in the sand. However, the process is far from efficient. And even in this scenario there needs to be some framework to allow time information to be communicated effectively.

As the work being controlled becomes more complex, both the planning process and the communication process benefit from the introduction of tools and techniques to assist in:

- the formation of the plan,
- retention of the planning information, and
- the communication of that information to others as needed.

Numbers of people need to be able to 'see' how the available time is planned to be used. Achieving this level of visualisation requires two key components:

- First, a consistent way of describing time both as elapsed units and as specific points in time, essentially a calendar.
- Second a way of representing complex data that allows the relationship between time and work to be seen and understood.

This section looks at how these two requirements have evolved over the millennia.

2.1 The journey to UTC

UTC, the Coordinated Universal Time Calendar that is the default global standard today has its origins in the Middle East beginning some 6000 years ago. Its antiquity helps to explain the unusual arrangement of numbers that make up the standard UTC calendar, 60 seconds in a minute, 60 minutes in an hour, 24 hours in a day and varying numbers of days in the months and years (Weaver, 2014 [3]).

2.1.1 The origin of 60 seconds and minutes.

Studies of protocuneiform clay tablets show that 60 was used as a basic unit of counting during the 'Uruk Period' in Mesopotamia; an Early Bronze Age civilisation that lasted from c 4000 - 3500 BCE (Ifrah, 2000).

The Sumerians built on this foundation starting in around 3500 BCE. In Sumerian culture astronomy, astrology, religion and the development of calendars were interconnected and important to their religion. Their calendar used a 360 day year and the Sumerians began the modern practice of dividing a circle into 360 degrees to represent the cycle of the seasons and the movements of the stars and planets throughout the year. Refinements continued through the Babylonian and Persian empires.

2.1.2 The origin of 12 and 24 hours.

The Ancient Egyptians developed a 24 hour day but with hours of varying length depending on the time of year. They used sundials to divide their day into 10 hours of daytime with 1 hour of twilight at each end of the day (making 12 hours in total). They also defined 12 hours of night-time; this is known from various tables defining the stars visible during the 12 hours of night (Weaver, 2014 [3]).

2.1.3 Consolidation and refinement BCE.

During the last couple of centuries of the BC era the Ancient Greeks combined these various systems into the modern form. In one development, they divided the day into 24 hours of equal length. In another, based on their knowledge that the world was a sphere, Greek astronomers normalised the lines of latitude and longitude to encompass its full 360 degrees.

Claudius Ptolemy expanded on this base to create minutes and seconds of arc. In his treatise *Almagest* (circa A.D. 150), he subdivided each of the 360 degrees of latitude and longitude into 60 parts, which were again subdivided into 60 smaller parts. The first division, *partes minutae primae*, or 'first minute', became known simply as the minute. The second segmentation, *partes minutae secundae*, or 'second minute', became known as the second. So, although the sexagesimal system is no longer used for general computation, it is still used to measure angles, geographic coordinates and time. But as we all know a year is not 360 days.

2.1.4 The Julian Calendar.

The UTC calendar with its 12 months of varying duration has a Roman origin. The Roman calendar underwent a number of improvements in the seven centuries before 46 BCE but still had a large accumulated error. In 46 BCE, Julius Caesar modernised and corrected the Roman calendar by increasing the number of days in most months to 30 or 31 days, to create a year of 365 days. These Julian months have the same number of days as modern months. To keep the calendar aligned with the earth's rotation around the sun an extra day is added to February every fourth year making the Julian year on average 365.25 days long. This calendar became the predominant calendar used in 'the West' for the next 1500 years. European countries used it, and took it with them to their settlements in the Americas and elsewhere.

2.1.5 The Gregorian calendar.

The problem with the Julian calendar was it gained about three days every four centuries compared to observed equinox times and the seasons. After 1500 years this error was significant and was corrected by the reform introduced by Pope Gregory in 1582.

The Gregorian calendar retained the same months and the same number of days in each month as the Julian calendar, but changed the way 'Leap Years' are calculated. The Gregorian reform modified the Julian calendar's scheme of a leap year every fourth year as follows: *Every year that is exactly divisible by four is a leap year, except for years that are exactly divisible by 100, but these centurial years are leap years if they are exactly divisible by 400*. This meant that the years 1700, 1800, and 1900 were not leap years, but the year 2000 was. This alteration reduced the mean length of the calendar year by 0.002%; and has resulted in a remarkably accurate calendar that will not need adjusting for several thousand years.

Adoption of the Gregorian calendar was very slow in Protestant and Orthodox countries; the last European country to accept the calendar was Greece, in 1923.

2.1.6 Year numbering.

The concept of allocating a number to each year dates from 525AD. The *Anno Domini* (AD) dating system was devised by Dionysius Exiguus replacing the Roman naming convention with year numbers. Dionysius based the start of his numbering on his estimate of the year of the birth of Jesus of Nazareth (year 1). Today, there is a generally accepted error of around seven years in Dionysius' starting point, but despite this his year numbering convention has remained unchanged though to modern times.

2.1.7 The 7 day week.

The concept of a seven-day week also comes from ancient Babylon. Prior to 600 BCE the Babylonians celebrated a holy day every seven days, starting from the new moon, and adjusted the length of the final 'week' in each month so that each month would commence on the next new moon. The Jewish calendar followed the Babylonian's; but used a continuous cycle of seven-day weeks, celebrating a holy day every seventh day. The early Christians were of course Jews and used the same calendar.

As Christianity slowly spread through the Roman Empire between the 1st and 3rd centuries, the Jewish/Christian week followed (previously the Romans had used an 8 day week). The Julian calendar with a 7 day week became standard across the Empire (including Britain).

The Germanic peoples also adopted the system used by the Romans (although many remained outside of the Empire – common calendars are useful for trade). However, they changed the names of the days to a Germanic naming convention based on their Gods. These names came into English usage as a consequence of the Anglo Saxon invasions during the 5th century and remain through to the present time.

2.1.8 Agreeing the UTC.

The International Meridian Conference held in Washington D.C. in 1884, created the foundation for a standardized global calendar. The conference agreed to define a 'universal day' based on local mean solar time at the Royal Observatory, in Greenwich England. This allowed the development of 'time zones' and the creation of the international date line in the middle of the Pacific ocean. Coordinated Universal Time (UTC) is based on the Greenwich Meridian and the Gregorian calendar.

2.1.9 Calendars - conclusion.

Having a defined way of describing a period of time and a precise point in time goes a long way towards allowing the effective management of time within a project. There were of course many other systems developed in different parts of the world and some are still used. However, the ever increasing importance of global communication networks has moved the modern world towards the universal adoption of UTC.

It's fascinating to think that this fundamental framework was fully defined with an accuracy of seconds per century in 1582 by monks using quills, parchment and abacus.

2.2 The invention of 'bar charts' and other representations of work and time

Knowing how long an activity should take, and when you want it to occur, is the essence of planning! Scheduling introduces constraints such as the availability of resources to adjust the expected timing of the work. This section looks at the way planning and scheduling information has moved from being data that is calculated, or innately understood, to formats that allowed people to literally see what was planned.

2.2.1 Duration Estimating.

The mathematics needed to calculate durations have been known for 3700 years or more. The Plimpton 322 tablet is a Babylonian clay tablet dating back 3,700 years. It has been identified as the world's oldest and most accurate trigonometric table. Researchers suggest that the tablet may well have been used by ancient scribes to make calculations for building palaces, temples, and canals (Mansfield, 2017). The Egyptians had similar capabilities but used different calculations.

The Ancient Egyptians were also capable of managing long lead time items. Probably the best-known example being the 43 granite beams used in the roof, and relieving chamber over, the king's burial chamber in the Great Pyramid. These blocks weighed between 30 and 60 tons each. Kozak-Holland (2011, p76) estimates a 10-year lead time was needed to cut and deliver the first of these to site. What is less clear is how effective these ancient builders were in coordinating effort across multiple work fronts and predicting the consequences of changes in the plan. This needs the ability to see the interrelationship between activities.

2.2.2 Cartesian representation of data.

The combination of numbers and geometry to create a graph was achieved by Nicole d'Oresme (later bishop of Lisieux) in the middle of the 14th century; he used this new tool to analyse quantitative relationships, and extended this doctrine to figures of three dimensions. He considered this analysis applicable to many different qualities.

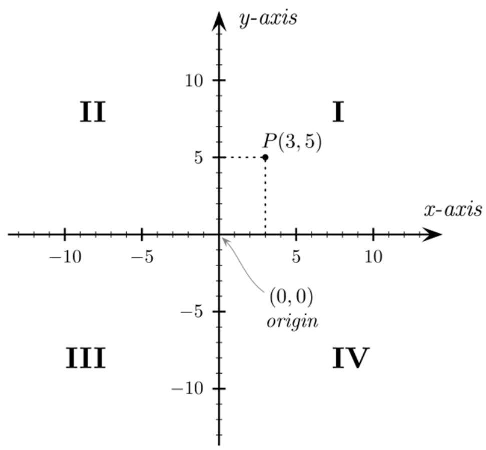

Fig. 1 Illustration of a Cartesian coordinate plane.
(Obtained from: https://en.wikipedia.org/wiki/Cartesian_coordinate_system)

Cartesian geometry advanced the ideas of Nicole d'Oresme. A Cartesian system uses a pair of numerical coordinates to specify each point uniquely in a plane. The coordinates are the distances from the point to two fixed perpendicular lines. This concept was developed by French mathematician and philosopher René Descartes (who used the name Cartesius in Latin) in 1637, and independently by Pierre de Fermat. Both authors used a single axis in their treatments and have a variable length measured in reference to this axis. The use of an 'x' and 'y' axis (Fig. 1) was introduced in 1649 by Frans van Schooten and his students (Weaver, 2014 [1]). This concept is the fundamental underpinning of graphs and charts.

2.2.3 Playfair and Priestly.

The originator of graphical schedule control tools appears to be Joseph Priestley (England, 1733-1804). His 1765 'Chart of Biography' is a bar chart (Fig. 2). It plots some 2000 famous lifetimes against a time scale, and "…*a longer or a shorter space of time may be most commodiously and advantageously represented by a longer or a shorter line.*" (Priestly, 1777 p.6)

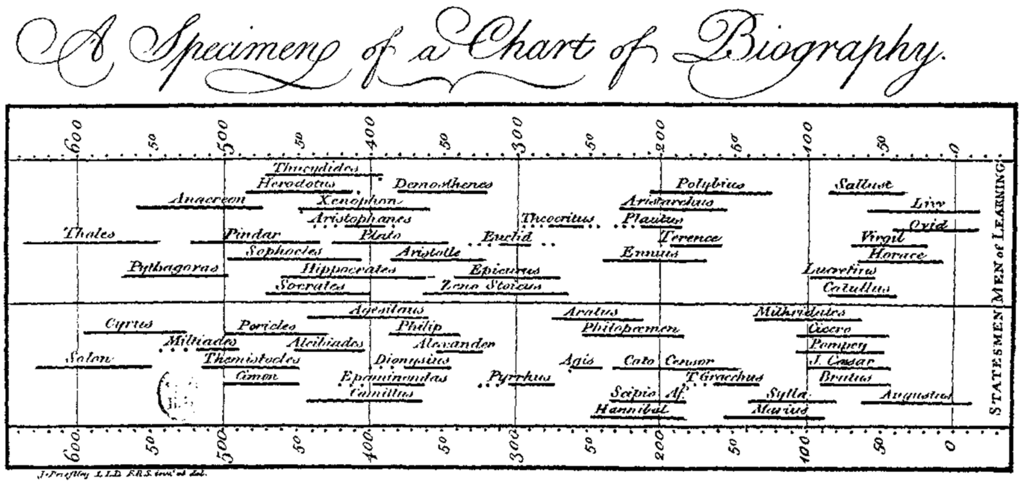

Fig. 2 A redacted version of Priestley's Chart of Biography (1765).
(Obtained from: https://upload.wikimedia.org/wikipedia/commons/9/98/PriestleyChart.gif)

Priestley also created his 'New Chart of History' (1769 – Fig. 3) which used similar concepts plotting the rule of 'empires' against geographical location and time.

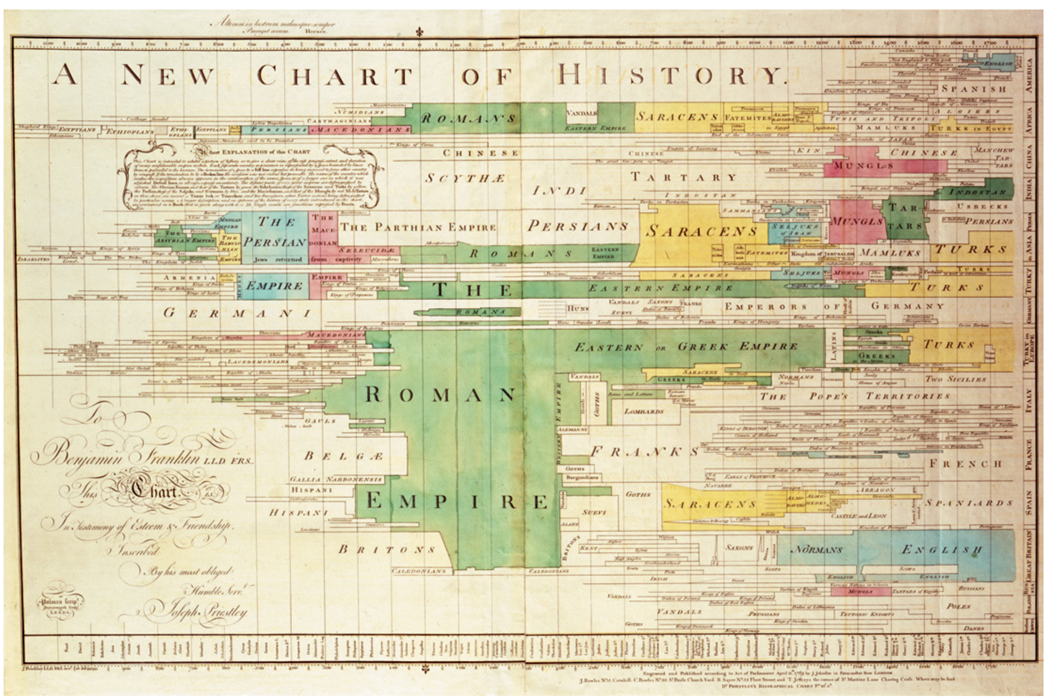

Fig. 3 Joseph Priestley's A New Chart of History (1769).
(Obtained from: https://en.wikipedia.org/wiki/A_New_Chart_of_History)

Priestley's Chart of History lists events in 106 separate locations. He wrote that: *'The capital use [of the Charts was as] a most excellent mechanical help to the knowledge of history, impressing the imagination indelibly with a just image of the rise, progress, extent, duration, and contemporary state of all the considerable empires that have ever existed in the world.'* (Priestly, 1777 [2] p.9) As Arthur Sheps (1999) in his article about the Charts explains, *'the horizontal line conveys an idea of the duration of fame, influence, power and domination. A vertical reading conveys an impression of the contemporaneity of ideas, events and people.'*

The wide distribution of Priestley's charts was facilitated by 'relief etching', an advance in the printing industry that enabled complex plates to be etched, printed, and then hand coloured at a fraction of the cost of earlier illuminated manuscripts.

William Playfair (1759-1823) is credited with developing a range of statistical charts including the line, bar (histogram), and pie charts. He used the same graphical concepts as Priestley in his '*Commercial and Political Atlas*' of 1786. Playfair's first Atlas contained 43 time-series plots and one histogram, both the number of charts and their sophistication increased during a series of later revisions of the Atlas (Fig. 4).

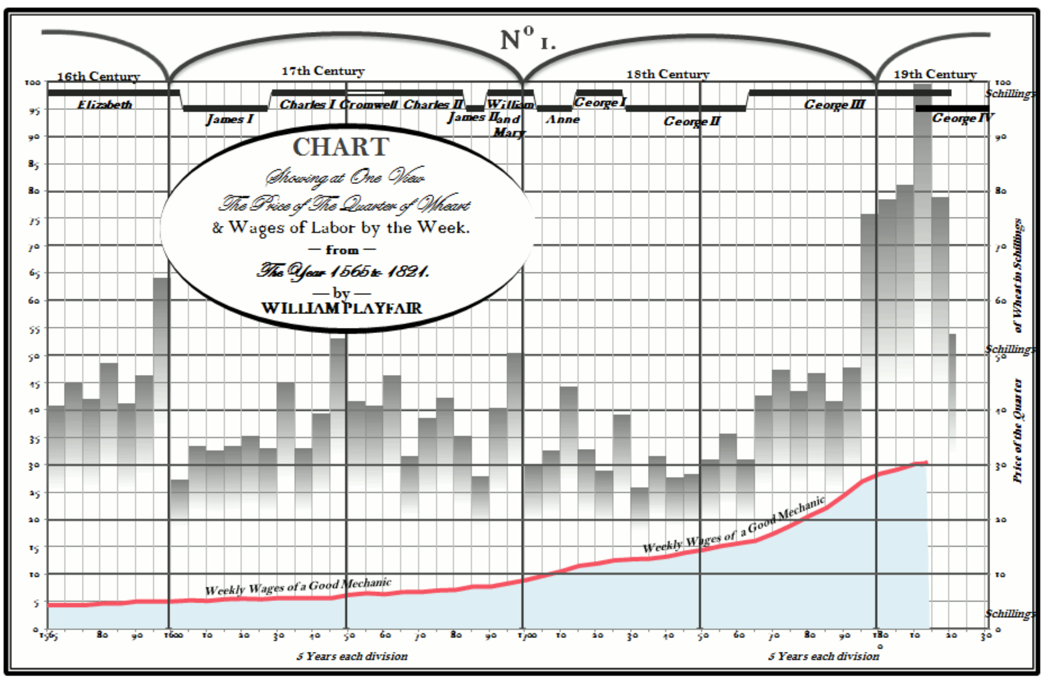

Fig. 4 One of Playfair's Charts from the 1821 edition of his Atlas.
(Tufte, 1983, p. 34)

The influence of Playfair's Atlas can be gauged from the fact that the charts included in the reports of the Royal Commissioners on the Great Exhibition of 1851 use exactly the same approaches to displaying data as Playfair had 100 years earlier (Fig. 5).

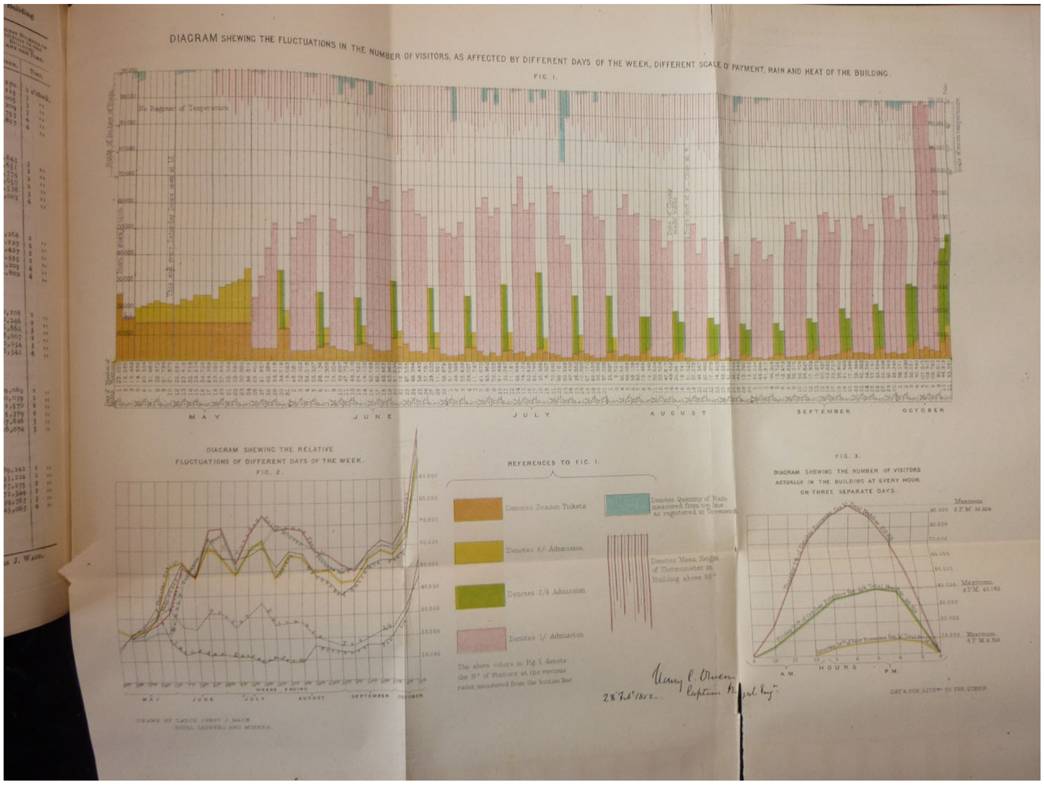

Fig. 5 A diagram from the report of the Royal Commissioners on the Great Exhibition of 1851. (photograph taken by P. Weaver with permission Victoria & Albert Museum)

2.2.4 Karol Adamiecki.

There is a gap in the records between the late 1700s and the late 1800s that is consistent with issues identified earlier in this paper. There is no reason why Playfair's charts could not have been adapted to communicate planned information and used to help manage the complex projects that underpinned the industrial revolution - but if they were used in this way, we have been unable to find any record. The use of charts for planning purposes suddenly appears in the record around the start of the 20th century; common sense suggests there was an evolutionary development of ideas leading to the work of Adamiecki and the others discussed below but the records are still to be uncovered.

Karol Adamiecki (1866 – 1933), was a Polish economist, engineer and management researcher. He developed a methodology for 'work harmonization' based on 'harmony of choice', 'harmony of spirit', and 'harmony of doing'. The latter requiring the sequencing and scheduling of activities to optimise production efficiency. The chart Adamiecki developed in 1986 for use in this method has become known as a Harmonogram, (or Harmonygraph / Harmonograf - Fig. 6).

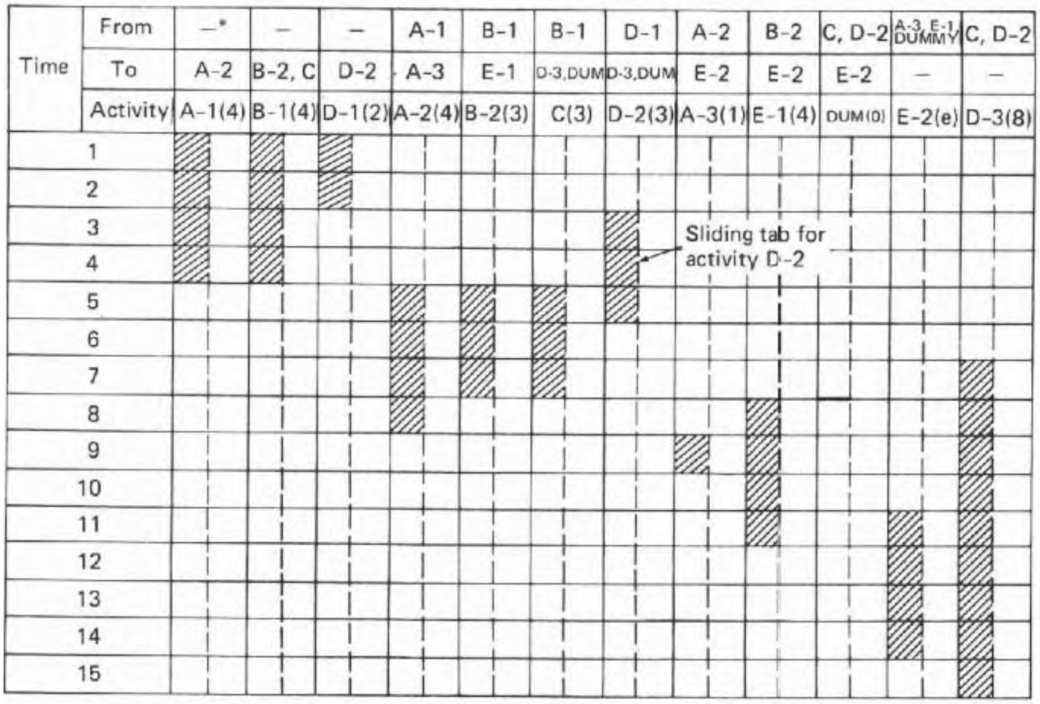

Fig. 6 A representation of a Harmonygraph (Moder, 1983).

The Harmonygraph has a date scale on the vertical axis (left hand side) and lists Activities across the top. Each activity is represented by a scaled paper strip, and the current schedule and duration of the activities were depicted by the position and length of the strips. Actual progress was recorded in the empty 'right hand' part of each column. In the header of the columns, the name and the duration of the activity and the lists of preceding and succeeding activities are shown. The strips representing the preceding activities were always to the left of the strip of the successor. The tabulation of each activity's predecessors and successors in the Harmonygraph ('from' and 'to'), and the mechanics of this process are the same as the calculations in a 'forward pass' in modern CPM, making it a distinct predecessor to the CPM and PERT systems developed some 60 years later.

This tool was part of a wider philosophy; Karol Adamiecki emphasised the importance of creating harmonious teams, practical scheduling, and compatible, measurable means of production. He claimed that companies implementing his method saw productivity increases of up to 400%.

Unfortunately, his work does not appear to have been widely distributed. The Harmonogram is known to have made a sensation in 1903 when Adamiecki first described it and the results of its application before the Society of Russian Engineers in Ekaterinoslaw – Poland was part of the Russian Empire at this time (Marsh, 1976). But despite its success and practical use, the original paper on the Harmonygraph was not published until 1931 (Adamiecki, 1931), and was (unsurprisingly) written in Polish. From an English/USA-scientific perspective this seems to be the reason his work was not well known in the 'West'. We suspect though, personal networks within Europe would have spread his influence throughout the continent.

2.2.5 The Langwies Viaduct and the Schürch' barchart.

The Langwies railway viaduct was built in Switzerland between 1912 and 1914 and formed part of the Chur to Arosa narrow gauge railway in the canton of Grisons. The project is of note (and therefore record) primarily because of the innovative use of reinforced concrete in the construction of the bridge (Schürch, 1915. Peters, 1996).

In his book *Building the Nineteenth Century*, Tom F. Peters (1996) suggests that the ability of builders to estimate construction processes with a fair degree of accuracy had grown from '*none at all*' when the Thames Tunnel was built in 1824-1843 to a stage where by the end of the century, '*contractors were generally so sure of their organizational abilities that deadlines became parameters of the building process*' (p285).

These early charts were a hand drawn static representation of the schedule. The bar charts correlate activities and time in a graphical display, thereby allowing the timing of work to be determined but sequencing is inferred rather than shown. However, these limited capabilities were fully utilised by Herman Schürch in the planning and managing of this difficult construction project.

The hypothesis we put goes beyond this straightforward proposition to suggest that the quality of the information in the 'Schürch' bar chart (Fig. 7) and its supporting histograms are far too sophisticated to be either 'one-off' or original, they appear to be part of a well-established engineering practice. The extract below translated from the original German article lends weight to the proposition scheduling was 'business as usual' at the start of the 20th century (in Europe at least):

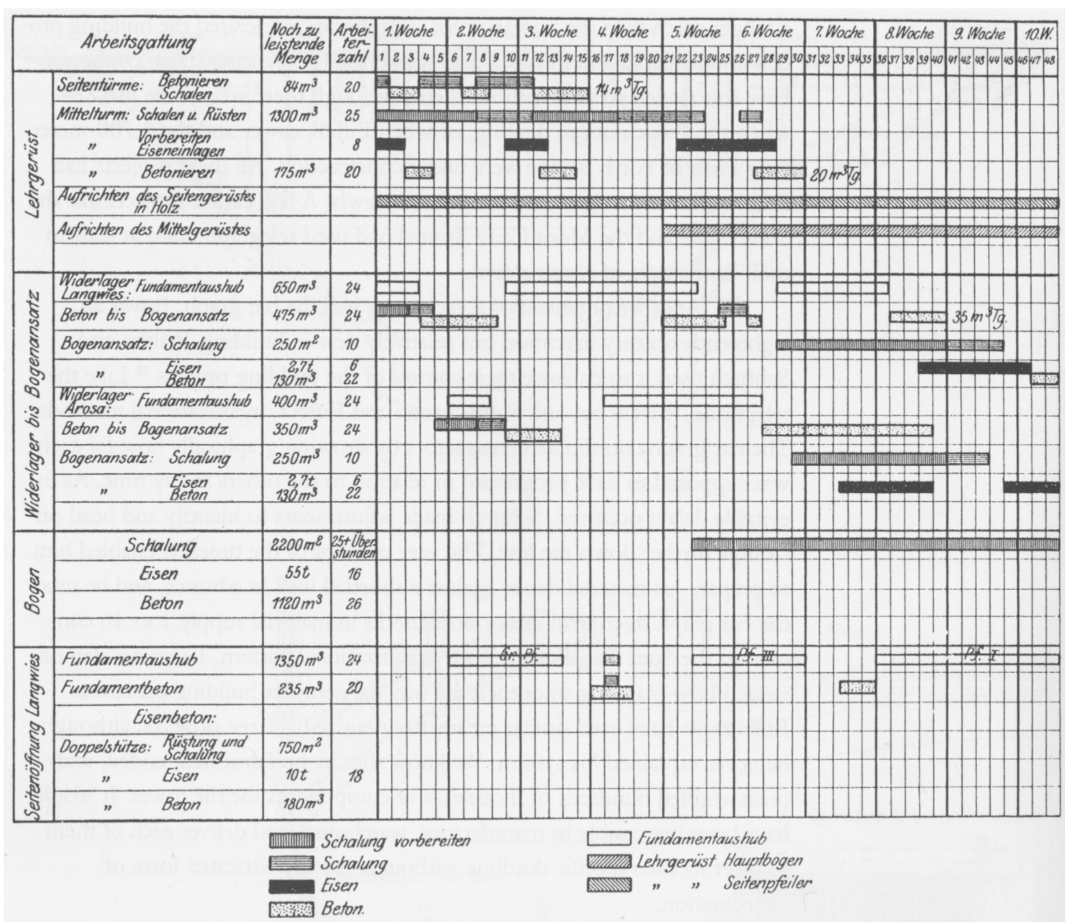

Fig. 7 The bar chart created by Herman Schürch in 1912
(Schürch, 1915, p233)

A very accurate graphical building program was set up for the execution of the work, ……. For that, each week was assumed to be five full days of real work, and thus all interruptions, by unfavourable weather, etc., were incorporated. By compiling the demands for each of the individual services in the construction program, a second table …… was created, which showed the total demand of construction materials and the overall effort; appropriate stocks were needed with regards to the uncertain and irregular supply, each had to be provisioned timely. The construction program was generally complied with, and the well-developed construction facilities, which have been designed mainly by Dipl.-Ing. J. Müller, just like the construction program, have excellently proven their value and shown to be very efficient, notwithstanding fairly significant investment costs. (Schürch, 1915, p235)

This bar chart and the supporting histograms that can be viewed in the original article strongly suggest 'project controls' were a well understood function at the end of the 19th century even if the concept of 'project management' was an idea that would not emerge for another 50 years.

2.2.6 Henry L. Gantt.

The importance of Henry Gantt to the development of project management and modern business management cannot be understated, but he deserves to be famous for the right reasons. Gantt's work had two primary components:

- A move away from Scientific Management's strict imposition of control onto the workforce to an approach based on learning and motivation to drive productivity.
- The use of numerous charts to visually display data designed to highlight issues and problems for management.

The vast majority of Gantt's charts were filled in at the end of each day. The only predictive chart in his books was the 'Load Chart' that was a bar chart, focused on planning the production sequence for batches of work through a machine shop (Weaver, 2012).

The concept of a 'Gantt Chart' did not arise during Gantt's life; he designed his charts as needed to provide valuable information to management. After his death, Wallace Clark published a book in 1923 called 'The Gantt Chart, A Working Tool for Management' that focused on one of Gantt's later charts used to measure the actual production of a batch against the planned rate of production over a few days (Fig. 8). This is the only 'Gantt Chart' (Clark, 1923).

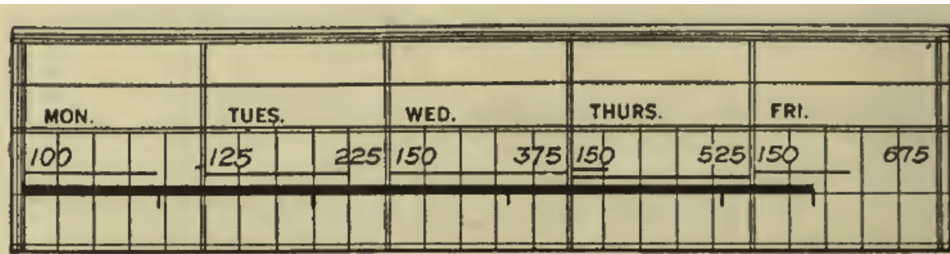

FIGURE 3. GANTT CHART SHOWING THE CUMULATIVE SCHEDULE AND THE CUMULATIVE WORK DONE

Fig. 8 A section of a 'real' Gantt Chart showing planned production per day and the cumulative total [numbers], the % production achieved each day as a thin line [Thursday achieved more than planned] and the cumulative total for the week (thick line). (Clark, 1923, p8)

While modern project management undoubtedly grew out of Scientific Management (Weaver, 2007), the misnomer of labelling bar charts 'Gantt Charts' and claiming they were invented by Henry Gantt seems to be a combination of American isolationism (Gantt's charts were the first of this type that many American managers ever saw and therefore 'all charts' had to be Gantt Charts) and sloppy scholarship that simply reiterates earlier incorrect assumptions (Weaver, 2013).

The simple facts are there is absolutely no evidence of any sort that links Gantt to project management (Geraldi, 2012), his entire working life and all of his publications are focused on improving the functioning of machine shops and factories. And while he is definitely a worthy successor to William Playfair in making information available to management via the medium of contemporaneously updated charts this process has nothing to do with the sort of planning Schürch was using his charts for.

Even the use of the term 'Gantt Chart' was fading out of common usage until the mid-1980s when for some reason the engineers developing Microsoft Project decided to call their 'bar chart' a 'Gantt Chart'.

2.2.7 Other representations of activities over time.

Two other significant approaches to identifying and managing time that appeared in the 1930s or possibly earlier are Milestone Charts that simply highlight dates for significant events to occur and flow line charts.

The most famous use of flowline was for the construction of the Empire State Building in 1931; this 103 story structure was completed in 1 year and 45 days (Fig. 9).

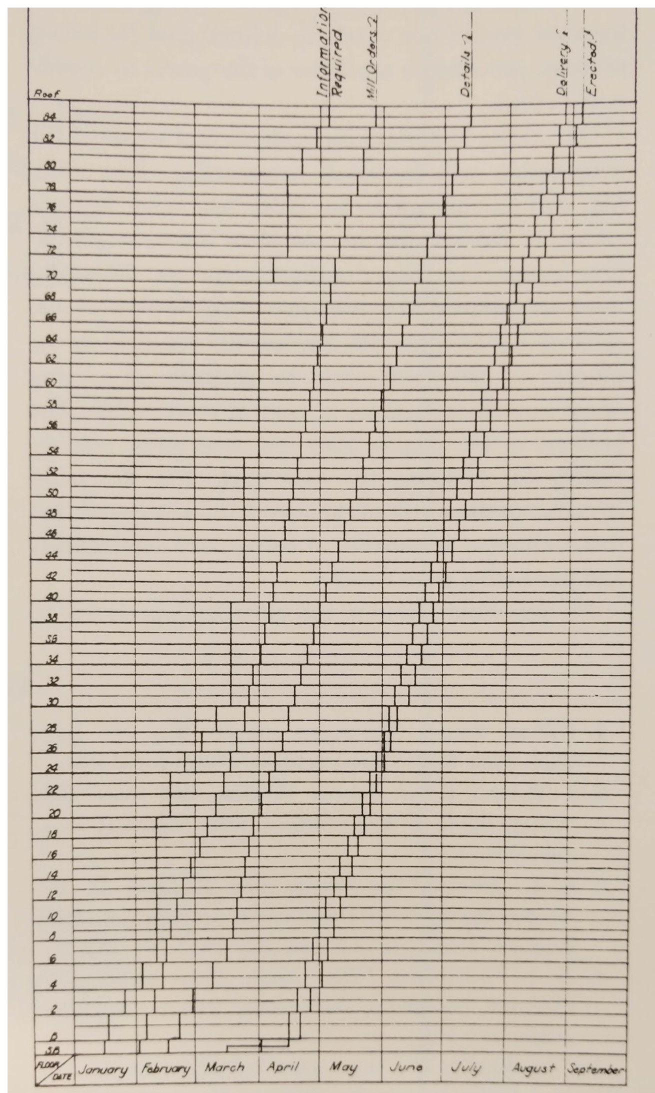

Fig. 9 Steel Delivery Schedule for the Empire State Building (Willis, 1998)

3 The shift from static to dynamic representation of time models

The major limitation of all of the scheduling techniques discussed to date is the static representation of data. To amend or update the schedule you either redrew the diagram or used an eraser to modify the existing diagram. Any change in one part required manual intervention to flow the consequences through to the balance of the diagram. Adamiecki's Harmonygraph went some way towards facilitating this. By pinning paper strips to the chart (which is why his bars are vertical) and documenting their predecessors, making the adjustments was easier but the process was still manual.

Developing dynamic schedules that automatically recalculated the consequences of a change as well as calculating the overall schedule itself needed the introduction of computing in the1950s.

3.1 OR, the underpinning of dynamic scheduling

Operations Research (OR) appears to be the seedbed that gave rise to the almost simultaneous development of dynamic scheduling methodologies in the UK, USA, France and Germany, that can be broadly classified as the 'critical path' approach to dynamic network scheduling.

OR is a branch of applied science that informs management decision making. It is an interdisciplinary science which uses methods such as mathematical modelling, optimization, and statistics to support decision making in complex real-world situations concerned with the coordination and execution of an operation within an organization. Most (though not all) OR involves carrying out large numbers of calculations. Consequently, it would seem likely the growth of OR was facilitated by the increasing power and widespread availability of computers from the 1950s onward.

OR started in the UK in the late 1930s; in July 1938, the British Air Ministry conducted a major war-readiness air-defence exercise using its new radar stations. This exercise highlighted serious problems around the need to resolve multiple, and often conflicting, streams of information received from various sources, so that the decision makers had access to the 'best available' information in real time. A new approach to information processing and decision support was urgently needed.

To resolve this critical issue, the Superintendent of Bawdsey Research Station proposed a crash program of research into the operational - as opposed to the technical - aspects of the air-defence system. The term 'operational research' was coined as a suitable description of this new branch of applied science. The first team was selected from amongst the scientists of the radar research group the same day (Operational Research Society, 2018).

What the scientists brought to their work were 'trained minds', used to applying the scientific method to develop and test hypothesis based on experimentation and data. The practice of OR was well established in the armed services both in the UK and in the USA by the end of the war.

From these roots, OR appears to have been the catalyst that triggered the relatively coordinated developments of various 'critical path method' (CPM) systems in the USA, UK and Europe. The documented links between OR and several of these developments strongly suggest that OR concepts and processes such as linear programming spawned the concepts of CPM. In addition, the regular cross-pollination of ideas between the different OR bodies through conferences and various publications would have been an ideal medium to facilitate the exchange of ideas between the various CPM pioneers prior to the emergence of 'project management' organizations more than a decade later.

Critically, OR was an area of interest to Jim Kelley. He was scheduled to give a paper to the Case Institute operations research conference in January 1957 when he was seconded to the Du Pont team being assembled by Morgan Walker that lead to the development of CPM. Kelley's paper to the OR conference went ahead with the inclusion of a 'simple linear program formulation' of the construction scheduling problem'; possibly the first formal recognition of CPM as a process (Kelley, 1957).

Project management organizations arrived much later and arguably grew out of the spread of CPM scheduling. Two of the earliest project management organizations were INTERNET and PMI (Weaver, 2007). INTERNET was founded in Europe in 1964, adopting the name an INTERnational NETwork in 1967. It subsequently changed its name to IPMA (International Project Management Association) when the 'other' internet started gaining popularity. PMI followed in the USA in 1969.

3.2 ADM or PDM, why the difference

The concept of developing the schedule as a dynamic network and the basic calculations are consistent across most of the early systems but two very different styles of presentation emerged. The 'activity-on-node' notation used by most variants and the 'activity-on-arrow' notation used by two parallel developments in the USA.

3.2.1 The origins of the activity-on-node notation.

The Precedence Diagramming Method (PDM) also called 'Activity-on-Node' creates a network based on nodes or events that have significance usually involving the work of an activity, connected by lines or links. This basic approach is consistent across several early developments where information on the networking approach remains; this includes:

- The Precedence Diagramming Method (PDM) method published in 1961 by Dr. John Fondahl in his seminal report: 'A Non-computer Approach to Critical Path Scheduling' in the USA (Fondahl, 1961).
- Metra Potential Method (MPM) developed in 1958 by Mr B. Roy in France and the UK.
- RPS (Regeltechnischen Planning und Steuerung) developed in 1960 by Walter and Rainer Schleip in Germany.

The Precedence Diagramming Method (PDM), or at least the development led by Fondahl overtly owes its format to process flow diagrams (Fondahl, 1987); he describes this type of diagram as 'circles and connecting lines' the name was changed to 'Precedence diagramming' after IBM computerised this approach to scheduling (Weaver, 2006).

The 'process chart' (ie, process flow diagram), invented by Frank and Lillian Gilbreth was the first structured method for documenting process flow (Gilbreth, 1921). 'Process Charts: First Steps in Finding the One Best Way to do Work' was presented to members of the American Society of Mechanical Engineers (ASME) in 1921. This presentation was widely acclaimed and their concept quickly found its way into industrial engineering curricula. By the early 1930s these ideas were also being taught to, and used by, business management. It seems highly unlikely this development stayed exclusively in the USA and the fundamental concepts of a 'process flow' and PDM schedule logic seem very closely aligned.

3.2.2 The origins of the activity-on-arrow notation.

The Arrow Diagramming Method (ADM) also called 'Activity-on-Arrow' is far less intuitive, ADM creates a network where the work is defined by arrows that connect at nodes, but the nodes generally have no function other than connecting the end of one or more arrows to the start of the next. The two development that used this notation were the original CPM developed by Kelley and Walker for DuPont (Kelley, 1989) and the PERT system developed for the US Navy (Malcolm, 1959).

Given James Kelley was a mathematician working for the US Navy prior to moving across to private business in the early 1950s, and PERT was a Navy development, the oral history collected by Chris Fostel and reproduced in Appendix A suggests the Quartermasters Corps is a likely origin for this notation. Fostel reports that 'Arrows and nodes' were used by the Corps for planning movements in the Pacific campaigns from 1942 onward and this methodology was declassified in 1956.

The narrative in Appendix A provides a reasonable explanation for both the notation and some of the key terms in CPM such as 'float' and 'slack'. However, the representations used by the Quartermasters Corps were static and their mathematics simple time based calculations. The innovations in CPM and PERT that occurred in 1956-57 used the same diagrammatic base, but applied advanced mathematics to the scheduling problems. Unfortunately, both sets of mathematical innovation largely faded from general use during the period from the mid-1960s to 2000. The potential revival of some of these advanced concepts in modern form is discussed in section 4.

3.2.3 The CPM variant of ADM.

The challenge the Du Pont team led by Kelley and Walker had to solve was 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 the time needed to complete a plant shutdown without significantly increasing cost (Fig. 10). The problem was identifying the 'right tasks' to compress (Weaver, 2006). This is a time-cost optimization problem that needs far more complex calculations than the simple time analysis found in most software today.

The concept of mathematical optimization has its roots in the 17th century. The branch of optimization used in this original form of CPM was Linear Programming (LP - also called linear optimization). LP is a method to achieve the best outcome in a mathematical model whose requirements are represented by a series of linear relationships (Dantzig, 1949), and is specifically mentioned by Kelley in a number of contexts around the development of CPM.

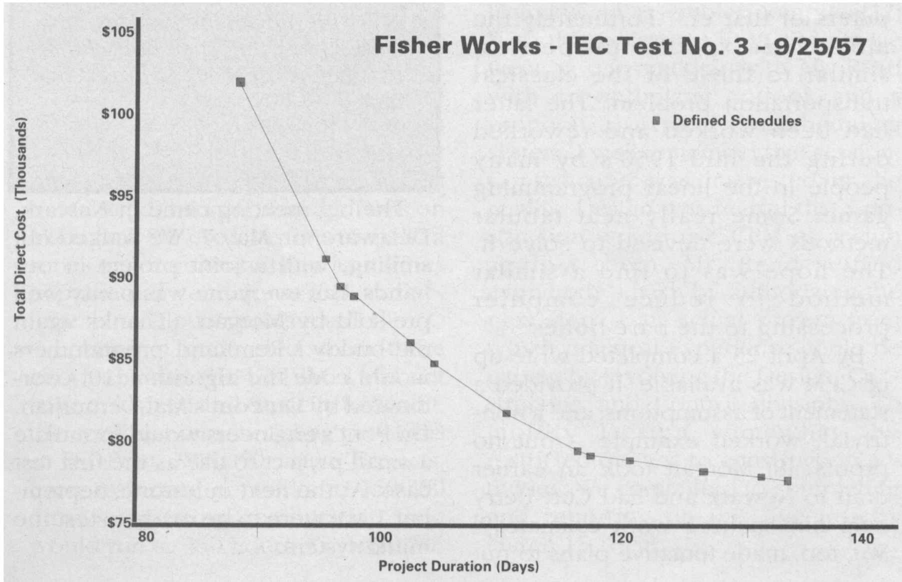

Fig. 10 Cost v Duration derived from CPM modelling.
(PM Network Vol III, No.2 February 1989, p9)

The data tables and computations involved in CPM may have made sense to the Du Pont team but confused management. To explain the process, the first ADM diagram was created freehand by Kelley as an aid to explain the overall scheduling concept to management after the computer had crunched the number and produced its results (Fig. 11). The untested assumption we make in this paper, is that the notation used by Kelley was informed by the diagrams developed by the Quartermaster Corps from 1942 onward (see Appendix A); he worked in the same general area of Navy.

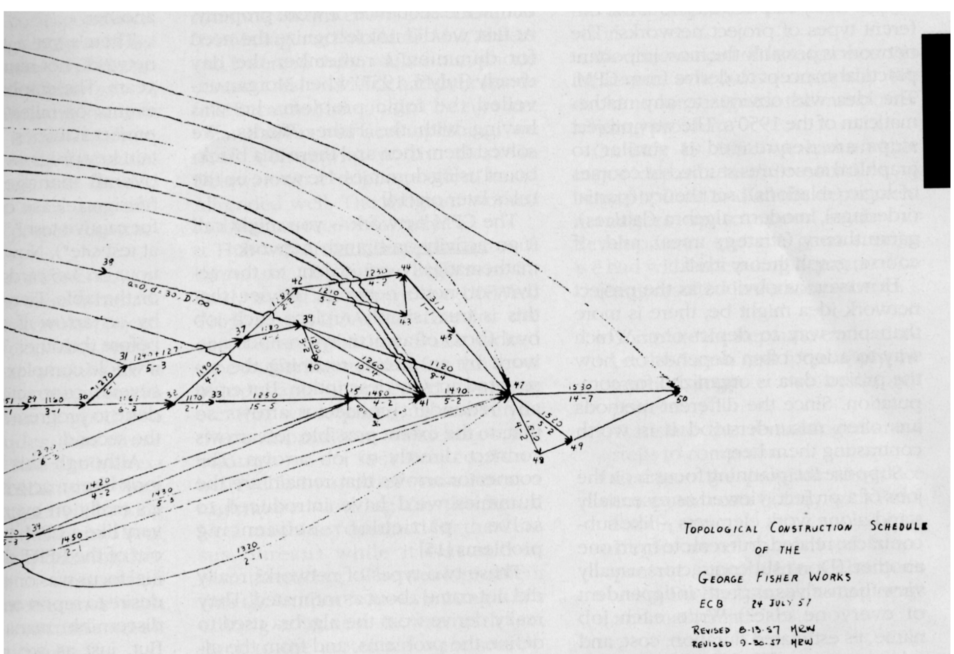

Fig. 11 Part of the Topological Construction Schedule of the George Fisher Works, 24 July 57.
(PM Network Vol III, No.2 February 1989, p10-11)

Unfortunately, the calculations used in this form of optimization were taking far too long to process on the available computers and obtaining the range data needed for the calculations was difficult. Consequently, when CPM was commercialised the mathematics were 'dumbed-down' to the simple CPM calculations we see today and all that remains of the original calculations is the concept of the 'i-j' nodes which came from the matrix needed to set up the optimization.

Kelley believed the difference between ADM and PDM network diagrams was a function of the algebra used to define the problem. In the algebra of parametric linear program used in CPM: '…*a job was denoted by a number pair (i,j) …the common subscripting used for indexing two way tables and matrices.'* (Kelley 1989, p12).

3.2.4 The PERT variant of ADM.

The PERT initiative also addressed a complex problem; answering the question '*what is the probability of achieving a target date?*' The mathematical approach used was simplified to fit within the capabilities of the available computers but provided an adequate answer given the uncertainty of the data being processed. No one had built anything like the POLARIS submarines and missiles before so every estimate was shrouded in uncertainty (Malcolm, 1959).

The success of PERT outside of the Navy is a fact of history. However, its use in the POLARIS program was limited and its results treated with suspicion. The primary use of PERT seems to have been to convince the US Congress their money was being spent in a controlled way. In that respect PERT was 100% successful!! (Weaver, 2006. Footnote w, page 12). The controls conundrum is the fact POLARIS was a very successful program of work, but its 'star control tool' was hardly used and was not trusted by management.

Outside of the Navy the concept of PERT became widely accepted and the shortcomings in the PERT approach to probability were overcome by the development of more powerful computers that could process Monte Carlo calculations in a reasonable timeframe, but his development has never become mainstream.

3.2.5 The regression to simple arithmetic.

The tragedy of modern project management is that sophisticated modelling applied in all of these interesting developments (including PDM) quickly faded from use. By the mid-1960s there was a consistent approach to CPM that used a single deterministic duration estimate for activities in both PDM and the two types of ADM networks (CPM and PERT). In these 'new models', optimization had disappeared completely, resource planning was simplistic at best, and cost projections were a simple aggregation.

Traditional PERT (despite its shortcomings) and Monte Carlo are still used occasionally to assess probability, but are not mainstream. Monte Carlo is a computer intensive analysis used to determining the impact of identified risks (variable inputs) by running simulations to identify the range of possible outcomes for a number of scenarios. A random sampling is performed prior to each run based on the variable inputs to generate the range of possible outcomes with a confidence measure for each. This concept was devised during the Manhattan Program (1944) but needed powerful computers for the technique to be of general use.

3.2.5 The regression to bar charts.
With the introduction of computers with a graphical user interface in the 1980s this regression continued. While the best of the available scheduling tools retained much of the capabilities found in the mainframe systems of the 1960s, the ease-of-use of quickly edited graphics saw the majority of project being scheduled using deterministic bar charts drawn 'on screen' rather than derived from logic based calculation.

To be fair, the number of projects expanded exponentially during the 1980s and beyond. The concept of the 'accidental project manager' became omnipresent outside of traditional project industries, and there was a consequential diminishment of skills and knowledge, particularly in the specialised area of project controls.

The failure of 'project management' to deliver on its potential may well be attributed to this loss of skills and diminished capabilities of the overall project controls function (CIOB, 2008). The correlation between the loss of project controls (scheduling) capability and the apparent increase in the rate of project failure may is a topic for future study. Resolving this skills shortage, at both the technical and managerial levels, is a challenge the profession of project management still has to adequately address.

4 The future

A number of trends are emerging that may reverse the decline in capability briefly discussed above, these include:

- The concept of BIM (Building Information Modelling) when fully realised has the capability of shifting the concept of planning from an abstract function to something resembling a 'virtual Lego® set' where the project team assemble the elements of the project in a virtual environment and the model applies artificial intelligence to constrain the timing of the work to manage issues related to resource requirements/availability, safety, etc. (Weaver, 2017).
- The ability of scheduling tools to apply optimization to the resource/duration conflict to better balance cost, resource utilisation and duration outcomes (similar to the concepts originally used by Kelley and Walker in 1957). Resource optimization is readily available in a number of commercial tools and leads directly to cost optimization but almost no one seems to use the capability.
- The ability of scheduling tools to incorporate active knowledge management to learn from previous project schedules and recommend options to planners as they develop a new schedule. This concept is very new. One product that has this capability is Basis (https://www.basisplanning.com).

The potential for more projects, more often, to get the *right people* in the *right place* at *the right time* to deliver a successful outcome is improving. However, having the technology is only part of the answer. The far greater challenge is convincing management to invest in effective project scheduling and controls, and to develop the skills needed to take the centuries-old practices outlined in this paper forward into the 21st century.

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Appendixes

Appendix A

An oral history on the origins of collected by Chris Fostel, an Engineering Planning Analyst with Northrop Grumman Corporation reproduced in full:

"I was told this story in 1978 by a retired quartermaster who founded his own company after the War to utilize his global contacts and planning skills. Unfortunately the individual who told me this story passed away quite a few years ago and I'm not sure any of his compatriots are still alive either. Regardless, I thought I should pass this along before I join them in the next life. I do not wish to minimize the work of Kelley and Walker. They introduced critical path scheduling to the world and formalized the algorithms. They did not develop or invent the technique.

The origin of critical path scheduling was the planning of the US Pacific Island hopping campaign during World War II. The Quartermaster Corps coordinated orders to dozens if not hundreds of warships, troop ships and supply ships for each assault on a new island. If any ships arrived early it would alert the Japanese of an imminent attack. Surprise was critical to the success of the island hopping campaign. The US did not have enough warships to fight off the much larger Japanese fleet until late in the war. Alerting the Japanese high command would allow the Japanese fleet to intercept and destroy the slow moving US troop ships before they had a chance to launch an attack.

Initially the quartermasters drew up their plans on maps of the Pacific Islands, including current location and travel times of each ship involved. The travel times were drawn as arrows on the map. Significant events, personnel or supplies that travelled by air were shown as dashed lines hopping over the ship's arrows. The quartermasters would then calculate shortest and longest travel times to the destination for all ships involved in the assault. The plans became very complicated. Many ships made intermediate stops at various islands to refuel or transfer cargo and personnel. The goal was to have all ships arrive at the same time. It didn't take the quartermasters long to realize that a photograph of the planning maps would be a devastating intelligence lapse. They started drawing the islands as identical bubbles with identification codes and no particular geographical order on the bubble and arrow charts. These were the first activity on arrow critical path charts; circa 1942.

The only validation I can offer you is that by now you should realize that activity on arrow diagrams were intuitive as was the term 'float.' Float was the amount of time a particular ship could float at anchor before getting underway for the rendezvous. Later when the US quartermasters introduced the technique to the British for planning the D-Day invasion the British changed float to "Slack", to broaden the term to include air force and army units which did not float, but could 'slack off' for the designated period of time.

You will not find a written, dated, account of this story by a quartermaster corps veteran. Critical path scheduling was a military secret until declassification in 1956. In typical fashion, the veterans of WWII did not write about their experiences during the War. No one broke the military secrecy. After 1956 they were free to pass the method on to corporate planners such as Kelley and Walker. A living WWII Quartermaster veteran, should be able to provide more than my intuitive confirmation.

Authors note: We believe the 'CPM' reference in the narrative above is focused on the modern simplistic version of CPM (which does use arithmetic similar to the Quartermasters Corps) – the narrator does not appear to be aware that the original CPM was a time-cost optimization model. As we outline in 3.2.3 above, the original CPM developed by Kelley and Walker's team used sophisticated optimization calculations and Linear Programming.

The process being described in this reminiscence is certainly similar to the simplified CPM time analysis on an activity arrow network but with two significant differences. The first difference between CPM and the Quartermaster's model is that different ships (and aircraft) left from different harbors (creating multiple start nodes – CPM has a single start node). The QM's scheduling objective was to ensure everyone arrived at the end point (the invasion beach) at the same time and presumably at intermediate harbors (islands) in sufficient time to allow convoys to be formed ready for the next stage of the journey. The second was the scheduling process was focused on achieving a coordinated completion to maintain the element of surprise, the modern equivalent is the 'as-late-as-possible' constraint during time analysis; the CPM default is for everything to be scheduled as soon as possible.

Where this oral history and CPM connect is in the format of the diagram. Kelley is on the record as stating the ADM diagram was developed after the CPM calculations were complete to 'explain to management' what had been accomplished by the computer. His choice of diagram style may well have been influenced by the QM style of drawing their 'schedules' described in this narrative, as are the use of terms such as 'float' and 'slack' – Kelley worked in the same general area of Navy prior to his move into private enterprise.

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Advanced Project Scheduling.

Time Management and Time Impacts.

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Introduction

There are a number of scheduling techniques that may be considered to be advanced and which provide significant benefits to the project when implemented. These techniques are used by experienced and professional planners and schedulers and contribute to successful on-time completion reputations. This paper will discuss these benefits, a description of the techniques, and evaluation of these techniques as well as reasons for use.

A. When and How to Develop a Project Schedule

Benefits of early planning and choosing the appropriate schedule for the project

The planning process should begin "as soon as the project is identified and continues as the project progresses through the various phases of the project life cycle from project conception to project completion and closeout."[2] Early planning facilitates brainstorming with the project team and stakeholders to identify effective and efficient methods of integrating the project design and construction into a finished product. Early planning is most valuable when it is developed with input from all stakeholders, which includes the Owner, Owner's financial team, the end user, any major vendors or equipment suppliers and major trade subcontractors. Best practices for early planning include the identification of: 1) the work; 2) the physical and fiscal parameters within which the team must confine their plan and 3) the time parameters on the project as a whole.

Inclusion of all elements of the work

In order for a schedule to provide an accurate plan for construction completion, the schedule must model the entire project scope of work. This is commonly accomplished by creating a Work Breakdown Structure (WBS). The WBS is a hierarchal structure that divides the project scope of work into manageable parts. The WBS is based on deliverables rather than actions (activities) to accomplish those deliverables, which might be scope packages such as the brickwork. The WBS should be designed so that it can be rolled up into deliverables, even if the lowest level of the WBS consists of trade packages or even greater detail, such as activities.

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[2] AACE International Recommended Practice No. 39R-06, "Project Planning – As Applied in Engineering and Construction for Capital Projects," page 4.

Involvement of construction staff and trade stakeholders

A construction schedule should not be developed in a vacuum by a single person, regardless of expertise. An effective schedule is a collaborative effort by the full project construction team who are involved or participating in the project. Without collaborative involvement, it is very difficult to gain acceptance, or "buy-in." Without buy-in, the schedule is much less likely to be used effectively. The schedule should not be the product of the president of a construction company, or even the project manager, but instead should be a result of collaboration among the full project team, generally consisting of the contractor's project management staff, subcontractors and key vendors. The smaller project management team, consisting of the project and assistant project managers, the project controls manager, the lead planner/scheduler and the major trade project managers, should take the lead in this effort, emphasizing the need for involvement of the full project team in the schedule development.

An efficient vehicle to facilitate cooperative collaboration is a development meeting or planning session. This meeting should be used to identify the sequencing and phases for the work. The interactions of various trade Contractors, such as precast wall panels and reinforced concrete footings and slabs, should be discussed and consensus achieved during this session. The result of this session should be a high level, low detail schedule that encompasses the full scope of work. This schedule will also depict interrelationships between trades and how the sequencing will meet the project restraints, such as phasing and completion.

Although this collaborative approach to the project schedule yields buy-in, a final review by the project management team should be made to ensure the incorporation of all constraints and sequencing. This final review increases the value of the schedule, and at least one study shows that reductions in cost growth of more than 10% result[3].

Role of Resource Planning and Loading

A construction schedule must account for the availability of local resources at the venue. The plan must include the right crews to complete the full scope of work for each activity in the activity duration and enough competent individuals on those crews. A resource plan that identifies the necessary crews, sizes, and compositions, allows accurate monitoring when this plan is compared to the actual resource usage on the project. This becomes particularly important for resolution of disputes in the event of performance problems or inefficiency claims.

Once the resources are identified and planned, they can be loaded into the project schedule software, allowing for automatic analysis and reporting. Most scheduling software is designed to produce reports that are organized by resources, showing how and which resources are applied across the activities. These reports can show situations where resources are over-allocated for the number of planned resources. One of the problems that can arise with resource loading is that the schedule is not detailed enough to allow activities to complete before other activities can start. The detailed schedule requires the more use of Finish-Start (FS) relationships between the activities, rather than the popular Start-Start (SS) relationships. The FS relationships require the predecessor activity to complete before the successor activity can start, while the SS relationships allow the successor to start before the predecessor is complete. The SS relationships often make it very hard to accurately load the schedule activities as they encompass more scope of work that tends to overlap. Resource loading is most useful when the resources flow cleanly from activity to activity,

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[3] "Scheduling Practices and Project Success," by Dr. Andrew F. Griffith, PE, 2005 AACE International Transactions, page 6.

and do not require varying degrees of resources to be applied across the duration of any single activity.

To illustrate the difference between a Finish-Start relationship and a Start-Start relationship, consider a metal stud installation activity that is succeeded by the hanging of drywall. If this is done with a FS relationship, and there are ten individuals installing metal studs, those individuals will work every duration day of the activity, and then terminate. The individuals loaded into the hanging of drywall activity begin and progress. Conversely, with a SS relationship, it is common for three of those ten individuals to move from the metal stud activity to the drywall activity towards the end of the metal stud duration, reducing the individual resource load from ten to seven. This approach will cause inaccuracies in the resource reports. As result, resource loading must be done carefully with appropriate activities, relationships, and sequencing.

Resource data permits accurate analysis is particularly helpful when a project faces a disruption leading to labour inefficiencies. When resources are accurately monitored, poor performance due to inadequate resources is more likely to be mitigated early from the periodic analysis process. One study has demonstrated that resource loading can result in 10% better schedule performance[4]. Resource data monitoring is a key ingredient in keeping a project on track.

B. Characteristics and Significance of the Baseline Schedule

The Baseline Schedule is the official project plan for accomplishing a project scope within an authorized budget and within a specified period of time.

1. Purpose

The primary purpose of establishing a Baseline Schedule is to define the plan for accomplishing the project by its required completion date. It is impossible to know if the project is proceeding according to plan if there is no plan. The Baseline establishes a means of monitoring and reporting progress that allows identification of schedule variances, the relative impacts of variances, and potential corrective action available. It is important to receive input from other project participants, if possible, and to achieve consensus on the Baseline Schedule, so that it can be used as a common measure of progress and status.

The Baseline Schedule should be a living document that is adjusted as necessary to accommodate changes and/or impacts. As changes arise, it may be necessary to adjust the plan, but the Baseline is always available for comparison back to the original plan.

There should only be one Baseline schedule. This schedule should be created by the Contractor and approved by the Owner at the beginning of the project. Later revisions may be necessary due to change orders or the need for a recovery schedule. These adjustments to the Baseline should be referenced by the reason for the revision in order to avoid confusion. The later revisions or versions are not the Baseline; only the original schedule is the Baseline. Later revisions can be designated as Target Schedules that can be compared with each other or the current working plan represented as an Update Schedule—but clearly distinguished from the original Baseline.

[4] "Scheduling Practices and Project Success," by Dr. Andrew F. Griffith, PE, 2005 AACE International Transactions, page 5.

There are many approaches to establishing a Baseline schedule, which is also commonly referred to as an As-Planned Schedule. Best practices dictates that the Baseline be prepared for the pre-construction meeting, and this is a goal worth setting. Although sometimes it is not possible, this should be done whenever possible. Having the project planned in advance of the pre-construction meeting is an important factor in a project's success.

a. Single Submission vs. Dual Submission Baseline Schedules

When there is insufficient time to develop a full Baseline Schedule submittal, it is helpful to use a two submission process. This process requires the Initial Project Schedule (IPS) to be submitted in an abbreviated timeframe, such as 45 days. A second submittal, consisting of the complete Detailed Project Schedule (DPS) is submitted later, such as 90 to 120 calendar days from the Notice to Proceed date. The IPS addresses the detailed work for the first 90 to 120 days, with summary activities shown for the rest of the project. The IPS should contain sufficient detail to represent sequencing and phasing to allow complete monitoring of the initial period. The DPS is then developed from the IPS, so that all DPS work is consolidated into the summary activities in the IPS. The U.S. Army Corps of Engineers uses this dual schedule process routinely.

The dual submission process is not as compatible with projects of shorter durations, such as a modernization or renovation project of three to six months. Dual submissions can be accomplished with shorter duration projects, but the timing requirements for submission of the schedules must be adjusted accordingly. Additionally, if the project delivery method is design build or construction management, the full baseline requirements may not be known until bid packages are developed, requiring significant adjustment in timing of the Baseline construction schedule.

Timing of the full DPS is often a difficult issue. At the outset of the project, the Contractor is often still negotiating with trades and may not yet have major subcontractors identified. The project management team is frequently distracted from focusing on an integrated Baseline. These realities support the option of a dual submission split of the schedule, as noted above.

b. Cost Loading or Resource Loading a Baseline Schedule

Resource and/or cost loading a Baseline Schedule complicates the discussion and requires considerably more information. The level and type of detail required from subcontractors for a resource-loaded schedule is entirely different from the level of information required for a schedule that is not resource-loaded. Resource loading is inherently more time consuming to develop, and requires considerable effort to compile and integrate resource information into the scheduling process.

Some organizations use a two tier approach, completing the Baseline schedule without resource or cost loading and then later loading when the information is available. However, this approach often generates changes to the Baseline, as the subcontractors start developing and compiling their costs and resources. Allowing thirty days to provide a full Detailed Baseline is often not enough time for large projects, although an ambitious goal. Depending on the duration and complexity of the project, it is quite possible that ninety days may be the shortest reasonable time for developing an effective Detailed Baseline schedule. However, the time frame for development of the schedule is a function of the dedication and support of the project team to that effort. Too frequently a Notice To Proceed is issued and project planning should begin, but Contractors fail to focus on planning because implementation has already begun. Optimally, there should be a planning period from

Notice to Proceed until mobilization, and this period should include purchasing, initiation of the submittal process, permit acquisition, and schedule development.

2. The Written Narrative

The purpose of the Narrative is to provide a summary of the work, explain the plan for construction and demonstrate that the schedule meets the specifications and contractual requirements. It is also important that the Narrative identify potential problems, and summarize the Critical Path.

The Narrative is the Contractor's plain-English description of the plan, means and methods, and the approach to resources. It is imperative that the Narrative match the Baseline Schedule. When the two documents do not align, it is important to address the misalignment and make corrections to ensure the Narrative and the Baseline align.

The major components of the Written Narrative are:

- General description of the scope of work.
- Identification of any area designations.
- General description of the sequencing, including any necessary legend.
- Identification of any deviations from the contractually mandated sequencing.
- Identify any phasing.
- Identification of all Milestones that are contractually mandated.
- Identification of any other Milestones.
- Identify Traffic Control Plan, if applicable.
- Risk management results, identification of problem areas of the project, and steps taken to limit risk.
- Any outstanding risks.
- Identify any road closings, or utility coordination shutdowns, or other conflicts.
- List and explain Calendars.
- Explain Adverse Weather planning methodology incorporated in the schedule.
- Identify any unusual logic relationships, such as Start-to-Start or Finish-to-Finish Activity Types and rationale.
- Identify purpose and use of all relationship lags.
- Explain any Activity ID coding.
- Explain any Activity Coding that is not self-evident.
- Explain any Resources in the Resource Dictionary that are not self-evident.
- Provide an abbreviated description of the Critical Path.
- Provide an abbreviated description of the Near-Critical Path.
- Provide description of methodology used to monitor Non-Critical work (Earned Value, Float Dissipation, activity variance, etc.)
- Specifically identify any Owner activities or provided items that are planned.
- Identify any procurement or fabrication problems.
- Identify all Date Constraints used in the schedule, with the Type and Date.

- Identify all Software Setting Constraints, such as Zero Total Float.
- Identify any potential conflicts with outside agencies, projects, or Contractors.
- For Enterprise software, identify all Global or Enterprise settings used that may not export correctly.
- Identify process used to validate as-built data.

3. Support for Baseline Schedule Review Practices

It is in the best interest of any project to get an approved As-Planned or Baseline schedule in place as soon as possible to ensure appropriate planning. An approved Baseline schedule permits accurate management of the project by both the Contractor and the Owner, and provides a basis for analysis of trending, completion predictions, delay, and development of validated documentation to accelerate resolution of any disputes. This is also true of schedule updates; approved updates contribute to project success through fewer disagreements as to the intent of the schedule in addition to providing the basis for analysis.

It is important for the as-planned schedule to model the Contractor's means and methods of construction. The schedule must meet contractual requirements as well as represent a reasonable approach to scheduling all work, including that work outside the Contractor's responsibility. If a schedule does not support these goals, the schedule potentially exposes the Owner (and the Contractor) to risks embedded in the schedule.

From a project Owner's perspective, a poorly developed Baseline schedule sets up opportunities for claims. A poorly developed Baseline schedule also reduces the opportunity for accurate monitoring or analysis of progress and/or delays. In addition, the Owner must ensure that the proposed Baseline schedule does not commit the Owner or the Architect/Engineer (A/E) to provide resources that may not have been contemplated. For example, if the Baseline presents shortened durations for submittal review, the Owner and A/E may not be able to accommodate with their planned resources.

Historically, scheduling tricks and traps allow a schedule to be manipulated to the Contractor's advantage. Those techniques include; missing scope, logic and activity duration manipulation, float suppression or sequestering, misuse of relationship types or lags, forced or predefined critical paths, misuse of calendars, false early completion and out of sequence work. Other traps for the unwary include hidden or unrecognized stacked trade work, shortened review and response durations, and concurrent delay creation or concealment. If these traps are not discovered or identified by the Owner at the schedule approval stage, activities may be pushed to late in the project, and result in associated stacking of trades, over-population of spaces, and the lowered work quality—all of which speak to the importance of a high quality schedule.

These manipulation techniques may be intentional or might be unintentional simply due to lack of experience or competence on the part of the scheduler. No matter the reason, if these techniques are included in the as-planned schedule, the Owner is at risk for claims for additional time and costs.

From the Contractor's standpoint, failure to gain schedule approval means there is no approved basis from which to measure delays or disruption. The Owner has not accepted any Owner-responsible work requirements, and the likelihood of proving entitlement to time extensions is reduced. The risk of failing to prove Owner-caused delays or disruption is greatly increased, requiring a significantly higher level of contemporaneous documentation.

4. Risk Management: Identifying the Risks

Schedules rarely incorporate any assessment of project risks. Best practices mandate development of a process to gather and use lessons learned from the collective experience of project management professionals in the development of a schedule. Risk assessment and management increases the likelihood of success, and lowers the risk of claims. Development of a process to facilitate identification, assessment and management of risk will improve results.

"Risk," as defined by Recommended Practice No. 10S-90, Cost Engineering Terminology, under "Risk – Project-Specific," includes the "uncertainties (threats or opportunities) related to events, actions, and other conditions that are specific to the scope of a project." Risks can fall into several broad categories, such as uncertain durations, specific potential events (e.g., unusually severe weather), or uncertainties embedded in the development of the CPM network. Each of those types of risk might be analyzed differently using different tools depending on the availability of software to support the analysis. For example, duration uncertainties are analyzed using Monte Carlo software, assigning a probability distribution to the range of pessimistic to optimistic estimates of duration. These simulations provide a range of project completion dates along with the probability of achieving each dates. Specific event risks are analyzed by lessons learned and experience using risk registers coupled with assessment of the likelihood and consequence of the risks (qualitative analysis) mapped to numerical probability and consequence factors, as well as Monte Carlo analysis (quantitative analysis). CPM network risks are analyzed by careful schedule review of the schedule components, as well as the use of Monte Carlo software to determine if the construction of the CPM network yields additional risks due to issues such as a large number of activities that have to completed before a single milestone or activity can start.

Managing cost risk in project bids has been recognized for years by the use of contingencies, but time risk in project schedules is rarely assessed or accommodated by contingencies. Not many Owners allow time contingencies unless the contingencies are held in management reserves outside of project management control. Risk analysis, as defined by AACE International, is "[a] risk management process step (part of risk assessment) and methodology for qualitatively and/or quantitatively screening, evaluating and otherwise analyzing risks to support risk treatment and control."

a. Risk Management

The general risk management process includes planning, identification of risks, qualitative risk analysis, quantitative risk analysis, and risk response. After this initial step, the identified risks that remain in the schedule are evaluated at each update and a new risk management process implemented at periodic stages during the project. This is covered by the Total Cost Management (TCM) Framework, the AACE's document representing the systematic approach to managing cost throughout the life cycle of the project, which defines risk management as "a systematic and iterative process comprising four steps":

1. *Plan – establish risk management objectives;*
2. *Assess – identify and analyze risk;*
3. *Treat – plan and implement risk responses; and*

4. *Control – monitor, communicate and enhance risk management effectiveness[5].*

One of the most important benefits produced from risk management is the collaborative effort of identifying risks and brainstorming the options for risk planning and response. This is similar to one of the primary benefits of planning, which is to involve the entire project management team in thinking through and brainstorming about how the project will be built. A risk identification and management workshop should follow closely in the footsteps of the planning session, involving many of the same stakeholders and improving the collaborative effort that is desired in partnering on a project, regardless of the nomenclature for the collaborative effort.

b. Risk Analysis

Schedule risks can be, at once, both threats and opportunities to the success of a project. Threats tend to reduce the success of meeting the project goals and opportunities often increase success. Risk analysis is the process of identifying, analyzing, qualifying and quantifying the risks, and developing a plan to deal with them. This analysis should be performed during Baseline schedule development as well as during schedule updates. Implementation of risk analysis should begin with early planning in both budgetary cost estimating and preliminary master scheduling in order to accurately predict the project completion date and final cost.

While there are numerous treatises addressing risk in construction projects, it is important to note that analysis of time-related risk has not been universally incorporated into planning. Assessing cost risk is more intuitive, although it is frequently addressed through the use of heuristics. Nonetheless, cost risk assessment has become more of a standard of the industry than time-related risk analysis. Most estimators will automatically add a contingency to a cost estimate to cover the risk of performance, usually based on the type of project and relevant circumstances. Estimators assess this contingency using their own rules of thumb developed over years of estimating as well as estimating manuals such as Means' Cost Data or Cost Works. However, when it comes to developing critical path method (CPM) schedules, time risk assessment and contingencies are either completely omitted or underestimated.

The purpose of this section is to provide an overview of risk identification, analysis and the assessment process as well as best practices for incorporation of risk management into CPM schedule development and maintenance. Any risk management program starts with an accurate CPM schedule, checked for quality, reasonableness, and appropriateness of the network model. Without a well-designed and developed CPM Baseline schedule, a risk analysis process will not be effective. The risk analysis depends upon accurate and consistent calculations of the network logic, the appropriateness of the sequencing and phasing, and a reasonable approach to estimating activity durations.

Most CPM schedules are not adjusted for risk but rather are developed as if there were one correct answer for the schedule's numerical data. Generally, activity durations are established by calculation of the quantity of work represented by an activity divided by the production rate, or by sheer "gut feeling" of the project manager or crew leader. This production rate is normally established by the Contractor's historical records or an estimating system, such as Means', that provides an accurate database of average production rates. Once those durations are calculated, they are often used as deterministic values. The use of the durations as deterministic values

[5] AACE International Recommended Practice No. 71R-12, "Required Skills and Knowledge of Decision and Risk Management," page 2

assumes that the durations are accurate and unlikely to change. This assumption ignores the fact that the schedule is attempting to predict how long it will take to complete an activity at some unknown time in the future, using an unknown crew composition, with variable experience, and working in unknown conditions. Risk management recognizes the inherent uncertainty in estimating durations and provides a process to consider other risks that may occur during the project. Probability distributions are the best way to model planned activity durations since durations are a function of productivity and productivity is usually not deterministic.

Schedule risks fall into several broad categories:

1. *General duration uncertainty;*
2. *Specific risk events; or*
3. *Network logic risks that exist or are increased as a result of the activity relationships.*

Each of these types of risk is analyzed differently using different tools. First, general duration uncertainty is the risk resulting from any of the following conditions:

- The deterministic durations estimated by the stakeholders are inaccurate, overly simplistic or are based on incorrect assumptions;
- The critical path identified in the deterministic approach may not be the same as the probabilistic critical path when risks are incorporated into the schedule;
- The combinations of durations, where pessimistic durations may stack along a path—because of logic relationships—will significantly extend the predicted completion date.

For duration uncertainty, many project managers become wedded to their initial estimations. Even in situations where the project team analyzes time risks, project managers' frequently assert that their initial estimates are the "most likely" durations. As this result is logical, the necessary discussion about the differences between deterministic and probabilistic schedule development rarely happens. Since the durations are estimates of future events, there is no certainty that the estimates will be accurate, and in addition, duration estimates are based on predicted crew production rates. Crew production rates are based on a number of variables, including the composition of the crew, the level of knowledge of the crew on the specific activity, weather conditions, the availability and condition of equipment, crowding of the workspace, and many others. All of these factors can affect the actual duration of the activity, making the original estimate unlikely to be achieved in some cases.

Using a deterministic approach with no risk analysis results in many assumptions being made in early development of the schedule and rarely, if ever, questioned or reviewed again during the project. These assumptions can lead to higher risks if they prove to be inaccurate.

Conversely, a probabilistic approach takes the concept of estimating durations based on average production rates to the next level. The probabilistic approach involves an examination of the range of possible project durations based on a spread (also known as the "distribution" in statistics) in the estimated activity durations, commonly called a three-point estimate. The name "three-point estimate" is derived from the three duration estimates it requires: the pessimistic, the most likely, and the optimistic. This process allows for a compilation of a range of durations that can be used in the risk analysis. This analysis also increases accuracy when there is a higher level of unknowns, as is often the case in early stages of any project, but especially with design-build or EPC projects where the design and procurement are under development at the same time as the schedule. This approach also addresses the risk of stacking inaccurate or changed durations along the same path, which can magnify the uncertainty of duration estimating by using inappropriate durations in the schedule. With the right risk management approach, the uncertainty of activity durations is reduced, and risk assessment accuracy is increased.

Use of the Monte Carlo technique simplifies analysis of duration uncertainties as well as risks from activity relationships and some specific event risks. Monte Carlo analysis runs a large number of iterations based on the spread of the duration estimates, so that many combinations of durations are used. This probabilistic approach recognizes that the more accurate way to model durations is through the use of statistics, where if enough iterations are run, the results will generally fall into one of the common probability distributions of activity duration. A probability distribution commonly seen and used is the “normal distribution,” which graphs into a bell curve with the most likely duration at the highest peak of the curve and smaller probabilities as the curve diminishes in both directions. An understanding of statistics is important in order to use Monte Carlo analysis in risk management, particularly in the selection of the probability distribution as well as the evaluation of the three-point estimates for use in the analysis. There are a number of features in the Monte Carlo computer simulation that produce interesting and useful results from the analysis, such as the ability to provide global or filtered duration estimate spreads and the ability to adjust risk by activity code. This entails filtering out certain activity codes, such as all exterior electrical work, and applying a unique probability distribution of durations to these activities.

The Monte Carlo analysis provides statistically significant “confidence levels" for the probabilistic prediction of completion dates and—since schedules are dealing with unknowns—enables the schedules to have higher probabilities of meeting the chosen completion date. There are a number of other benefits in running Monte Carlo simulations on schedules that dramatically increase value. One of these benefits is the determination of which activities are most likely to appear on the critical path. This is called the Criticality Index in some software, and the charting that results is often referred to as a Tornado Chart. The Criticality Index provides the listing of activities most likely to be critical in any of the various simulation runs. Knowing which activities are most likely to appear on the critical path at any given time can be used to design appropriate monitoring of those specific activities.

The Monte Carlo simulation methods are available in numerous software packages, such as PertMaster (now acquired by Primavera Systems which was acquired by Oracle and renamed Primavera Risk Management), which can be linked to the CPM software by the same package. There are also spreadsheet versions of Monte Carlo simulation techniques, such as @Risk, published by the Palisade Corporation. The use of the three-point estimates risk analysis originated in the late 1950s during the Navy's Polaris missile program. That program was called PERT, for Program Evaluation and Review Technique. PERT developed independently of and concurrently with CPM methodology and used the three-point estimate process to provide a weighted average duration for use in the network calculations.

The construction industry appears to be moving away from the risk assessment of duration uncertainty because duration risk is greatly reduced by the use of good schedule monitoring. With careful and consistent review, pessimistic durations are much less likely to stack up and create a delay. As a result, the industry is moving towards the use of risk drivers, which are similar to the specific event risks discussed below.

Specific event risks are potential impacts on the schedule that may or may not occur, such as accidents, unusually severe weather and other events that are hard to predict. Specific event risks include several types of risks that are analyzed by several methods, but the initial step is a brainstorming session in which project team members identify as many potential risk events as possible and create a risk checklist of those events. The process of identifying potential risks to a project is a valuable effort that helps the project management team start thinking about risk issues and also produces a more realistic schedule.

Another type of specific event risk includes additional scope of work activities that may or may not happen, activities that are present in the schedule but may require unplanned multiple cycles to complete, or activities that have significant variability. It is important when brainstorming these risks to review historical records and experiences to determine which of these types of risks may occur. These risks are often dependent on other factors such as the personnel involved, the type of project, or the timeframe and budget.

There are several methods to analyze specific event risk. Modelling a specific risk by creating a linked group of activities to represent the scope of work related to the risk (called a "what-if scenario") is one good way to attempt to determine the potential ramifications of the risk. This same approach would be taken during a project if the specific event risk actually occurred. The project management assesses the potential ramifications of the event and the schedule impact. In this situation, a prospective Time Impact Analysis (TIA) should be prepared. A prospective TIA uses the current updated schedule, and a linked group of activities that model the changed condition or specific event are inserted into the schedule to re-evaluate whether the finish date changes. This linked group of activities is called a fragmentary network, or fragnet. The amount of impact to the finish date is an indication of number of days that the changed condition affected the critical path and delayed the project[6]. Specific risks can also be incorporated into a Monte Carlo analysis to provide a probabilistic approach to modelling the risks.

Network logic risks are also important to risk analysis. Network logic risks are those that generally occur as a result of project management decisions made about the sequencing and relationships of activities determined by the activity relationships. If a number of paths originate or terminate in one activity, there is a significantly increased risk of delay to critical path activities causing delay to the project.

Network logic risks include any risks that predominately relate to the schedule network such as activities that occur at a "hub" or convergence point. A single activity that controls multiple activities of subsequent work, such as environmental controls, dry-in, above-ceiling inspections, or temporary traffic relocation, will cause serious delays and disruption if not completed on time. Activities that require the same resource and have tight sequencing predictions are at a much higher risk of failure if resources are not as available as the schedule predicted. Failure of one activity will likely be reflected in all other activities that require that same resource. These network logic risks are often discovered only through technical analysis of the schedule components. Best scheduling practices include a thorough review of the schedule to identify these risks and develop a management plan.

Once the types of risk are understood, a good risk management plan should be prepared, including a brainstorming meeting with the major project stakeholders. A master risk register is an invaluable tool for facilitating the brainstorming session, which is often called a Risk Workshop. This register is a logical place to collect lessons learned on a corporate level from many project experiences. With a

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[6] An excellent description of a prospective TIA is provided by the AACE International in the Recommended Practice No. 52R-06, "Time Impact Analysis – As Applied in Construction."

complete risk register, organized by industry and type of risk, the process of brainstorming moves quicker and is focused with a more comprehensive list of risks.

Just as a schedule development session should be a dedicated meeting with the project management team, the risk workshop should be treated as a stand-alone process, requiring participation by the major project stakeholders. At a minimum, the project management team should participate, but the involvement by others provides valuable insight from those with other views and experiences.

The risk workshop deliverable should be a fully developed risk register, identifying all potential risks to the schedule, regardless of the party responsible for the solution, along with a Risk Response Plan.

c. The Risk Response Plan

The most valuable deliverable from the risk workshop is the Risk Response Plan, which should be shared with all project stakeholders. The Plan addresses each project risk by one of four types of responses; Avoided, Transferred, Mitigated, or Accepted. These options should be discussed so the stakeholders understand how each risk should be addressed.

Risks are Avoided by contractual risk-shifting, re-sequencing, or float management. Risks are Transferred through procurement, contractual risk-shifting, change management, or insurance. Risks are Mitigated by resource analysis and/or compression. Risks are Accepted and managed by project controls techniques during the project. Working from highest priority to lowest priority through the final overall risk ratings, each risk is addressed by one of the four types of response.

The most important step in risk management is implementation of the Plan. If the Risk Response Plan is not implemented, then the time spent will be purely academic. It is essential that the project management team implement the Risk Response Plan and ensure that the responses are incorporated into the schedule, and to enable the process to continue during routine updates.

The Risk Response Plan documents the risk management efforts, including all open risks that must be monitored and updated during the routine updates. With Enterprise Primavera scheduling software, the Risk module can be used to record and track risks and risk drivers on an ongoing basis until the risk is resolved. The project management team should also schedule time during the progress of the project to conduct a simplified risk workshop, and that time period is monitored so that a new risk identification cycle can be initiated. Risk management reporting should be provided with each schedule update. It is frequently helpful to summarize the Plan for the top priority risks and provide a matrix describing those risks and planned responses. A monthly summary of the balance of risks left in the schedule also assists the project management team in planning.

d. Documentation of Risk Implementation

The Risk Response Plan should become part of the project Construction Management Plan, under either the Risk Section or the Project Controls section. Any revisions to the schedule that are required as a result of the Risk Analysis and the Risk Response Plan should be incorporated into the schedule, and the risk-adjusted schedule should be published to the project team after final quality control check.

5. Contingency Planning

Contingency time planning is an important aspect of project planning. Specifically, it is an amount of time added to the base estimated duration to allow for unknown impacts to the project schedule. Contingency time planning can also be used to achieve an increased level of confidence in the estimated duration of the project. Many projects have little to no contingency planning, as the industry has not generally accepted the need to include time contingency planning the way it has accepted the need to include cost contingency planning into a cost estimate.

When contingency time is added to a project, it is frequently carried outside of the project schedule as a time contingency, often called a management time reserve. Sometimes Owners will allow project time contingency, but it's more often a function of the risk assessment process. A time contingency takes the bare durations and sequencing from the subcontractors, and uses risk analysis to allocate additional time for mobilization and demobilization, inter-trade coordination, weak subcontractors, and high-time-risk portions of the project. That time contingency is achieved inside the project rather than as management reserve. Optimally, the process should be transparent so that everyone knows what time may have been added to the schedule for contingency.

C. Reviewing the Baseline (Initial) As-Planned Schedule

1. Constructability

AACE International defines Constructability [as] "the optimum use of construction knowledge and experience in planning, design/engineering, procurement, and field operations to achieve overall project objectives."[7] Schedule constructability includes a number of issues, from physical constructability to preferential decisions in assigning logic to the activities.

Constructability also includes phase constructability; aligning the schedule with the appropriate phases to ensure that the work is planned appropriately for contractual phasing. The phasing may require less than optimum use of spaces, resources, or materials, but contractual phasing must be accommodated.

Additionally, Owners should consider paying for a full project bid and constructability review to ensure efficient and buildable drawings. A constructability review identifies missing information from the contract documents that can be supplied prior to mobilization. Any constructability issues will require time to address, either in the middle of productive work with the risk of delaying the project, or initially if discovered through a constructability review. This is the classic "pay me now, or pay me later" concept. Cleaning up constructability issues before the Contractor is mobilized will reduce costs and time during the project.

A prudent project Owner will specifically describe the requirements for the schedule submission by bidders and/or the awarded Contractor. Best practices require a bid or tender schedule to be submitted for evaluation of the offer or proposal. This bid schedule will demonstrate whether the Contractor has planned the project sufficiently for a reasonable depiction of their intended means and methods. Resource and cost loading of this tender schedule will help illustrate the plan and ensure that the Contractor has anticipated the required resources to construct the project.

[7] AACE International Recommended Practice No. 48R-06, Schedule Constructability Review," 2009, page 2.

After the award, Owner management should set up a partnering session or some type of less-formal dialogue session with the Contractor. This session, regardless of the moniker, should facilitate transparent and open discussions about contract documents and the as-planned schedule.

This session should also address change orders and a discussion about the best process for dealing with change in a timely fashion. Ideally, the prospective Time Impact Analysis (TIA) should be used for evaluating time impacts.

a. Physical Constructability

Sometimes referred to as “hard logic”, physical restrictions to construction will drive the ability to complete work in any phase or sequence. Generally, physical limitations are the first consideration in developing a schedule. If the masonry walls cannot be laid until concrete footings are installed, that physical limitation will not allow those walls to be started prior to completion of the appropriate section of concrete footings.

Careful development and quality control of the completed schedule are vital to producing physically constructible project schedules. These issues, however, are usually the easiest ones to discover when reviewing schedules.

b. Resource Requirements and Limitations

One of the primary reasons for project schedule failure is inadequate resources to complete the activity durations in the planned time and sequence. This is particularly true when there is significant concurrent work requiring multiple crews working at the same time in the same locations. Inadequate resources, whether due to individuals or crews, will adversely impact any schedule. Inadequate resources also results in constant re-planning after scheduled dates are not achieved and the following month’s revised plan requires more and more concurrent resources to meet the schedule.

Although resource limitations are usually preferential logic issues, a schedule must be developed to accurately accommodate the available resources at the time and location of the project. Without taking into account these available resources, a schedule is simply an idealized approach to construction. Sometimes construction professionals claim that “Projects are planned by early dates, but implemented by late dates.” This is a tacit admission that the project schedule was not developed with proper consideration of available resources, and is therefore not a legitimate schedule.

Activity durations are estimated by quantities multiplied by the estimated production rates. Those production rates are based on estimates of crew composition and size, and the assumption that the crews are capable of achieving those production rates. If the crew composition or size is inadequate, production will stall, and delays will ensue. As production slows, more and more work must be performed either concurrently or with greater and greater numbers of individuals or sizes of crews. It is vital that the original plan is based on available resources, operating at the necessary production rates, to achieve the planned durations.

Unfortunately, it is easy to manipulate resources and production rates, and schedulers often revise the baseline schedule, or fail to fully develop it based on resources, in order to accommodate the contractual completion date. A review of the available total crew count contemplated by the schedule is an appropriate way to validate the resource logic.

c. Other Preferential Logic Issues
Other preferential logic can be based on the site logistics, site layout or the type of construction. This can include working from a tight corner on the site towards the areas with more access, or scheduling based on the availability of subcontractors. A three-story precast parking garage that requires the precast panel fabrication as well as the reinforced concrete contractor to install, could be sequenced to fabricate all of the panels simply because the concrete contractor cannot be on the project early enough to take earlier produced one-story panels.

2. Deficiency Concerns and Recommendations

Project Owners must take care in reviewing the proposed baseline schedule, and determining whether the schedule should be approved. From the Owner's perspective, the primary reasons not to approve an as-planned or baseline schedule often relate to the severity of the problems with the schedule, which can be subjective. Those problems typically result from poor modelling of the project plan, and include misalignment between:

- The schedule and the written narrative,
- Missing written narrative, missing scope of project work,
- Under-development of specific trades compared to much more highly developed scope of other trades,
- Critical or near-critical paths that include inappropriate high proportion of Owner-responsible,
- Third-Party-responsible work activities,
- Missing or inappropriate logic relationships,
- Failure to include resource logic, network problems such as inappropriate use of lags,
- Calendars, or dangling activities,
- Cost loading problems,
- Resource-loading problems.

The more the existence of a number of the problems noted above in a proposed schedule, the higher the risk that the Contractor has inadequately addressed or analyzed time related problems.

3. Early Completion

An Early Completion Schedule (ECS) or Early Finish Schedule is a schedule that shows earlier completion of the project than the contract requires, generally leaving float in the submitted schedule. The purpose of an early completion schedule is either: 1) to complete in less time than the contractual project duration to save money on general conditions cost or field overhead; or 2) to provide a buffer or contingency time to mitigate the risk possible productivity problems causing a late finish. An earlier completion date may evolve from routine schedule updates, after time has been gained and the update predicts an earlier completion than contractual completion. However, that scenario is generally not defined as an Early Completion Schedule [ECS]. Only an as-planned or baseline schedule is a true ECS.

An Early Completion Schedule has significant implications to both the Owner and the Contractor. Depending upon the contract language, a Contractor who is prevented from achieving an Early Completion Date by the Owner or causes beyond its control, may assert a claim for additional costs.

An Owner may not want an Early Completion date, and may not want the risk of additional cost claims from the Contractor.

While the project documents are being developed for the bidding or tendering process, the issue of ECS should be addressed in the contract documents, so that all bidders are required to address the Owner's requirements in the preparation of their bid. Attempts to eliminate the risk of an ECS may be handled in several ways: 1) requiring that the submitted as-planned schedule shows the project encompassing all the time from notice to proceed to contractual completion; 2) requiring a constraint on the contractual milestones and not allowing float in the as-planned schedule; or 3) clearly stating that early completion schedules will not be accepted.

ECS Risk from the Owner's Perspective:

The first step for an Owner who receives an ECS is to check all activities that are Owner responsibilities or activities that will drive Owner responsibilities, to ensure that the ECS does not impose accelerated or additional requirements on the Owner, such as shortened review time, or early equipment delivery, or coordination with other projects earlier than possible. Any of these conditions should be cause for rejection of the schedule irrespective of the early completion issue.

Second, it is important to identify any notification, even constructive, from the bidding Contractor of the expected time frame, or the absence of general conditions costs in the budget for the full contract time. Both are factors suggesting that an ECS is planned.

The Owner should consider the numerous ramifications to accepting early completion. Some of the considerations are:

- Owner will pick up any maintenance and operating charges from the early completion date.
- Owner may have to adjust its schedule for procurement of equipment.
- End user may need to occupy early in order to assume operating costs.
- Owner employee salaries may start earlier than planned.
- Infrastructure coordination may be difficult (utilities, etc.).

The time between the early completion and contract completion could be treated as "contractor-owned float," if the ECS is accepted under certain conditions:

- Any Owner changes that occur in this period may be compensable even if the changes do not drive project completion beyond the ECS, resulting in compensable extended conditions costs.
- The Contractor could take this float time as necessary, so an ECS might still finish on the contract date without penalty.

The Owner should consider whether it is possible to take possession of the project on the ECS date, considering the risks. If it is possible, the recommended practice is for the Owner to issue a change order with a reduced completion date, at no cost, to align the contractual completion date with the ECS. This eliminates the discussion about float in the as-planned schedule, and places the liability for completion on the ECS date on the Contractor, and decreases uncertainty about the predicted completion date. If the Contractor's purpose in submitting the ECS is to minimize general conditions costs, generally he will be supportive of this approach.

On the other hand, if the purpose of the ECS was to build some contingency into the schedule, the Contractor is less likely to support a no cost change order adjustment to the schedule. In that event, the Owner should discuss the Contractor's needs and the reasonableness of the schedule in relation to those needs. This discuss will either result in the Contractor withdrawing the request for an ECS, or the Owner and Contractor reaching a meeting of the minds regarding cost and schedule needs. While the industry has tended not to support the use of schedule contingency, there are practical reasons why it might be necessary to provide a contingency, among them that time is an expiring resource so allocation of contingency and management of the contingency would be a factor in successful on-time completion. AACE has a Recommended Practice specifically to address best practices in use of schedule contingency[8].

There is still a contractual risk to the Owner of delayed early completion that should be considered and accommodated. Although contracts may contain provisions prohibiting Contractors from completing projects early, courts have narrowly interpreted these provisions and require them to clearly preclude early completion in order to exempt the Owner from liability for early completion delay damages.

ECS Risk from the Contractor's Perspective:

Often when a Contractor submits an intentional ECS, the schedule may still have unknown float issues in that the schedule may not represent the entire scope of work. When the procurement process is not included in the schedule, the calculations showing that the project can be completed early may not be accurate. Additionally, resource planning is generally not well thought out and results in inaccurate and misleading float values that show the project can be completed early. However, once the accurate resource planning is implemented, the early completion buffer frequently disappears. These issues illustrate why it is so important for a Contractor to perform a careful quality check on the as-planned schedule to identify any problems with the logic. With the Owner's option to simply reduce the contractual completion time to the ECS submission, it is very important that the Contractor is confident about the completion prediction.

If a Contractor is comfortable that the ECS is achievable, specific steps should be taken to protect his position. The first step is to put the Owner on notice that the Contractor needs to finish according to the ECS submission in order to meet the profit goals included in the cost estimate used for the bid. This notice should be specific, referencing the amount of general conditions estimated as well as any resource allocations needed at the end of the project. The more detailed the notice, the more likely that a discussion between the Owner and Contractor will be initiated to negotiate a reasonable solution during schedule review. This pre-project negotiation mitigates the likelihood of a dispute later in the project.

While providing notice of the Contractor's intent to complete the project early is advisable for improving Owner-Contractor relations, the Contractor is not legally required to give notice at the inception of the contract in order to later recover for early completion delay damages. Instead, the Contractor is required to show that it intended to finish the project early when bid. A Contractor can prove its intention by giving the Owner notice or by bids or estimates. However, notice to the Owner is the best way to prove that the Contractor intended to finish the project early.

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8 AACE International Recommended Practice No. 70R-12, "Principles of Schedule Contingency Management," 2012

Another risk for the Contractor with an ECS is Owner-directed change orders that result in the Contractor remaining on the project longer than the ECS date. When an Owner-directed change order delays the project, the Contractor may have a claim for the unabsorbed field overhead or general conditions incurred if the delay prevents the Contractor from completing the project early. Therefore, the risk of Owner-directed change orders elevates the need to document and prove ECS. In order to recover for costs and time for delayed completion of an ECS, the Contractor must be able to show from the inception of the contract that: 1) the Contractor intended to complete early; 2) the Contractor had the ability to complete early; and 3) that the Contractor would have actually completed early absent the Owner's actions[9].

The importance of establishing the adequacy of an ECS as-planned schedule cannot be overstated. Before decisions are made concerning the ability of the project team to finish a project earlier, all of the many factors affecting success must be considered. Ownership of float is a factor that impacts success, and early planning is essential.

4. Adverse Weather Planning

Planning for adverse weather is a methodology that requires a combination of historical weather research relating to the project venue and statistical analysis. Thorough study and planning for adverse weather produces accurate and reliable schedules. Unplanned adverse weather reduces productivity on a project to a greater extent than planned adverse weather. A schedule that does not take into account that the history of adverse weather conditions at the project site during the project timeline, there is a high likelihood of date slippage, with the resulting reduction in credibility of the schedule.

Adverse weather planning involves choosing a methodology that is credible, reasonable, and easy to maintain while requiring as few schedule revisions to maintain the system as possible. Historical adverse weather records are available and have been interpreted for use in project planning. In addition, planning for adverse weather using a transparent and reasonable methodology provides a baseline for the project expectations for adverse weather losses. Weather planning should be coordinated with critical path activities that would be most impacted by weather. Unusually adverse weather, defined as weather that is worse than the historical records would suggest, can be analyzed for extensions of time requests compared to this benchmark of planned adverse weather. Generally, unusually adverse weather would entitle the Contractor to an excusable time extension.

Weather planning mitigates the likelihood that weather will cause a delay to the end date that could have been avoided by historical study. Moreover, schedule and equitable adjustments are generally not available to Contractors who fail to consider expected weather in their schedules.

Best Practices in Planning for Adverse Weather

Optimal planning requires scheduling appropriate activities for the expected weather conditions. Examining the full scope of work and allocating the schedule accordingly is critical to successful project planning. Owners with rigid completion requirements may fund mitigation of weather conditions in order to expedite the work. However, the norm in construction planning is to schedule

[9] "CPM Scheduling for Construction – Best Practices and Guideline" book, Carson, Oakander, Relyea, Section 2.6.4.1, "Early Completion Schedules – Intentional" , PMI, 2013

"around" the weather, to lessen the cost of mitigation and the impact of anticipated adverse conditions.

The most commonly disputed impact arises when work activities are appropriately planned for good weather periods in the baseline schedule but changed conditions shifts the "good weather" activities into time periods of expected adverse conditions or non-work periods. With appropriate updating, the schedule should show a delay resulting from the changed condition into time periods of anticipated adverse conditions. Analysis of the schedule update or changed condition should prompt a request for time extension and/or request for equitable adjustment to mitigate the weather impact.

The most often implemented accommodations for adverse weather include:

1) using weekends for "make-up" days;
2) using an activity just prior to substantial completion to house adverse weather time for the entire project; and
3) the use of weather calendars. These methods are described below and discussed in more detail in a book[10], co-authored and co-edited by Carson in the sections specifically written by Carson. The topic has been further explored in a Recommended Practice co-authored by Carson[11].

Weekend Makeup Days

The use of weekends to make up for lost weather time is a popular methodology because it is simple, requires no work to implement, and appears on the surface to be a legitimate approach. The downside to this approach is that it does not provide dedicated weather planning. This approach can be effective when the project climate does not typically demonstrate large swings in adverse weather. When using this methodology, it is important for the Contractor to advise the Owner in writing that its plan is based on an historically derived source, which is limited in reliability. The problems with this approach include:

- This approach fails when the planned non-work days exceed the number of weekend days.
- Use of this approach is best when the Owner agrees that the limit of weather impacts is two days a week before excessive adverse weather merits a time extension.
- An Owner could take the position that the Contractor has planned for two days of adverse weather in each 5-day workweek.
- The weekends may not coincide with the timing necessary to accommodate the required make up time.
- Subcontractors must agree to the concept at the front end of the project, or use of this approach invites requests for payment of overtime for weekend work.
- Contractor supervision will have to work on the extra weekend workdays, which can impact morale and productivity.

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[10] "CPM Scheduling for Construction – Best Practices and Guideline" book, Carson, Oakander, Relyea, Section 2.6.5, "Planning for Adverse Weather" , PMI, 2013

[11] AACE International Recommended Practice No. 84R-13, "Planning and Accounting for Adverse Weather," 2013

- Any Owner furnished supervision or inspection will have to be available if weekend work is needed. Some municipalities may not be willing to inspect on weekends at all.
- This approach does not account for any seasonal variations.
- This approach reduces the Contractor's frequently-used opportunity to use weekends to make up for low productivity weeks.

Activity Used to Store Predicted Adverse Weather Time

Another common practice in scheduling for adverse weather planning is to insert an activity just prior to the "substantial completion" milestone or the "dry-in" milestone that houses adverse weather time. This methodology is popular in some federal government contract work. This approach sums all of the expected adverse weather non-work days and uses that total as the duration for a weather activity (sometimes called a "weather bank," "weather allowance activity" or "weather bucket"). The weather allowance is inserted into the schedule immediately prior to the substantial completion or dry-in activity. Only activities that are sensitive to adverse weather would then be predecessors or terminate at this activity. Activities that are not sensitive to adverse weather should not have the weather allowance activity as a successor. This allowance duration is typically monitored on a monthly basis and reduced as necessary to accommodate the amount of actual adverse weather experienced.

With the weather activity approach, it is important that the schedule update reconciliations include an analysis of any lost weather time that exceeds that month's planned time. This requires a separate list of monthly planned time for comparison. Without this reconciliation, there is a risk of consuming necessary weather planning when there should have been a time extension due to unusually adverse weather.

The actual adverse weather is closely monitored by the project team, with a determination each week of the total number of days lost due to adverse weather, and summing those days for the month. This determination includes consideration of whether project resources were unable to work enough to achieve productivity, often defined as more than half a day, as well as secondary conditions such as a muddy site impacting work activities. A report is then generated that identifies the actual adverse weather days and the weather allowance activity duration is thereby reduced. As the project progresses, it is important that the project team determine whether the amount of the weather planning activity duration is adequate to complete the project. If it is not, then a new assessment and assignment of the weather allowance activity is recommended to cover the remainder of the project duration and season.

The use of an activity to house the total adverse weather planning time has the following disadvantages or risks:

- All activities in the project or prior to the "substantial completion" or "dry-in" milestone are subject to, and potentially impacted by, adverse weather.
- If the schedule has all activities as predecessors to the weather allowance activity, then float is sequestered in the activities that are not subject to adverse weather.
- If the successor to the weather bank activity is dry-in, there may be no adverse weather planning for site development work.

- The inclusion of the weather-planning activity at the end of paths such as dry-in will artificially reduce float values along those paths, making those activities more likely to appear on the critical path.
- The critical path is less reliable because the network does not calculate properly for those activities that are falsely affected by the weather bank activity. The result is very similar to too much logic that tends to increase the number of activities on the critical path.
- This approach sequesters float when the project does not experience adverse weather; the float that is gained should be returned and available to the project. This must be done by periodic analysis and reduction of the weather allowance activity's duration as appropriate.
- The weather bank requires additional work in monthly monitoring and adjusting of that weather bank activity.
- Weather planning is no longer related to time-of-year level planning, which eliminates consideration of the time of year adverse weather risk. Instead, every need is satisfied by reduction of the weather bank without this consideration.
- Early dates of the activities in the schedule do not include weather planning so if there is adverse weather, early dates are too optimistic. The ONLY activity in the entire schedule which has dates adjusted by weather planning is the milestone that is the successor to the weather planning bank activity.
- This approach does not allow the schedule to automatically and immediately predict delay when activities are shifted into heavier weather periods. There may be a delay that is caused by a changed condition that shifts weather-related activities into a period of worse adverse weather than originally scheduled. With a weather calendar, when the weather-related activities are shifted, the project automatically shows a delay. With the weather bank, the delay goes unnoticed at the time because the time is just taken from the bank activity, and mitigation is actually provided by removing weather planning from the rest of the activities in the schedule.
- The delay is only a weather delay after the weather bank is used up, so it doesn't matter when the actual delay occurred. This is contrary to good delay and forensic analysis philosophy.
- Often no consideration is given to who owns the float in the weather bank activity.
- The Owner may develop an unrealistic feeling that there is contingency time in the schedule and tends to forget that this contingency is really only for adverse weather and not available for the Owner's use.

Weather Calendars:

The use of weather calendars to model adverse weather is a very popular method of weather planning. Calendars should show non-work days on a monthly basis, with the non-work days selected at random across the weeks of the calendar, using the industry average number of days as determined in the interpretation of adverse weather data. The assignment of the non-work days should be over a seven-day week since weather records are compiled on seven-day weeks, which will cause some of the non-work days to fall on weekends.

This method allows the CPM network to automatically calculate and keeps the adverse weather planning in the appropriate season, forcing weather-related activities to take on the appropriate non-work time of the season as they shift due to changing conditions. This approach accommodates delay analysis and provides accurate predictive results as a result of adverse weather in any conditions of delay and disruption.

Weather days in excess of the planned adverse weather numbers are deemed unusually severe weather days and as such would normally be subject to a time extension. In order to track these normal adverse weather days, and plan for the activities that they affect, the following procedure should be applied:

- Develop the baseline schedule based on a 5-day workweek.
- Identify all activities that are subject to weather and code them for easy filter selection.
- Develop a separate project calendar (the "weather calendar") within the scheduling software, showing the appropriate number of adverse weather days per month. Ensure that this calendar matches the 5-day workweek.
- Using the predicted days of adverse weather per month, apply the count of days randomly across either the month or, assign them in the weekly proportion across each week. Spread the days out so they are not contiguous because that will tend to show gaps in the work and confuse the project team.
- Include the weekends in the full week of assigning non-work days, since the National Weather Service tracks calendar-week adverse weather, not work-week adverse weather.
- Apply this calendar to the activities affected by weather activities, identified in step 2.
- Calculate the new finish date and compare to the benchmark. If the project shows a delay, check to see if the delay is due to unusually adverse weather conditions.
- Review planned non-work days that may appear in a contiguous fragnet, such as between completion of formwork and the concrete pour. This type of planning could interrupt the smooth and necessary continuous work.

Using this approach, should a spate of unusually severe weather days occur, the project manager has the documentation to accurately request an extension time. This methodology has allowed the Contractor to reasonably and responsibly plan for weather and accurately track the number of days that were in excess of historical averages. In most cases, in order to successfully achieve an extension for "unusually adverse weather," the weather must not only occur (and be documented), it must also affect the completion of a critical path activity (i.e. an activity with no float and/or on the longest path).

It is also necessary to define what a lost weather day really means on any given project. Do job records show that work ceased, or manpower was effectively reduced to approximately half of the typical workforce, or the work was shut down for the day or a large part of the work day, and that the work cessation was not at the end of the workday? Lost weather time can also include weather resultant conditions, such as mud days when the site is too muddy to use equipment.

Not properly accounting for these days will have two potential impacts. First, the schedule will be flawed and will not realistically represent when the work will be performed. Secondly, the impact of any delay will be masked because of the inaccurate calendar, and in absence of any reasonable plan, a claim will likely be rejected.

The use of weather calendars has the following disadvantages or risks:

- There is an effect on the float path from changes in calendars as activities move from a project calendar to a weather calendar and back.
- If a schedule is organized by total float, there will likely be a jump in the total float value when the calendars change from regular calendar to the weather calendar and back.
- If the weather calendars are not actualized, then actual durations for those activities that are affected by weather will not be accurate.

Of the several methods to plan for weather, the use of weather calendars has the most advantages and fewest disadvantages.

Less Desirable Adverse Weather Planning Techniques

There are several less desirable techniques for adverse weather planning. One such approach increases durations to accommodate adverse weather. This approach reduces transparency such that durations no longer can be verified by calculations of resources and quantities. The amount of time that is concealed in the durations is unknown, so that no one knows whether the durations include contingency for adverse weather. Another serious drawback is that this method fails to accommodate a dynamic schedule. The additional time for adverse weather that is added to the duration is only season-related in the static baseline schedule. As soon as the project schedule changes, the durations become inappropriate for the activity season schedule. For example, activities with increased duration for winter work, upon slippage, will be scheduled for summer work while activities with no planning will be scheduled for winter work.

5. Third Party Interference Planning

In order to ensure that a schedule provides a reliable means to monitor and predict completion dates, it is important that the entire scope of work of the project is included. A scheduler must also consider and include likely third party impacts to the schedule. If permits are required to tap into a sewer system, and if the tap is required for project completion, then the schedule must include that activity. Project unknowns, like weather, must be predicted with as much accuracy as possible. However, known influences—although within the control of a third party—must be included in the schedule. Without these known requirements included, the schedule does not accomplish its purpose of providing a vehicle to monitor project progress.

D. Reviewing the Updated Schedule

While the updated schedule reviews follow many similarities of the baseline schedule, the added complexity is the presence of actual progress data. Review of the update requires two components: those that deal with the as-built portion of the project schedule and those that deal with the as-planned portion of the update.

1. The As-Planned Portion of the Updated Schedule

From the Owner's perspective, the importance of careful review of the as-planned portion of the updated schedule submission, the activities and logic to the right of the data or status date, cannot be overstated. Unfortunately, many Owners will often only look at whether the milestone and end dates match the contractual requirements and if so, the submission will be approved. However, if the Owner fails to sufficiently analyze the submission, it can endorse use of a poorly developed schedule. Approval of a poorly developed schedule enables opportunities for claims set up by the Contractor's baseline schedule. It also reduces the effectiveness of the schedule to act as the basis for analysis of both completion and delays. In addition, the Owner may unwittingly "approve" requirements for submittal review or other functions that the Owner had not contemplated.

The recommendations for review of the baseline or as-planned zero-progress schedule submission are generally also legitimate for the as-planned portion of the updated schedule.

Owners must scrutinize the as-planned portion of schedule submission to ensure that it is not one that can be manipulated to the Contractor's advantage. Owners should look out for missing scope, logic and activity duration, float suppression or sequestering, misuse of relationship types or lags, forced or predefined critical paths, misuse of calendars, false early completion and out of sequence work. Other problematic issues include hidden or unrecognized stacked trade work, shortened review and response durations, and concurrent delay creation or concealment. A well-planned schedule will not allow activities to be pushed until late in the project, exposing those activities to the risks of stacking of trades, over-population of spaces, and the resultant lowered quality. Regardless of whether these manipulation techniques are intentional or simply due to lack of experience or competence on the part of the scheduler, Owners should not approve the submission in order to mitigate risks of potential claims for additional time and costs.

Other issues that Owners must consider when reviewing a schedule submission for approval:

- Misalignment of the schedule and the written narrative,
- Missing written narrative,
- Missing scope of project work,
- Under-development of specific trades compared to much more highly developed scope of other trades,
- Critical or near-critical paths that include inappropriate high proportion of Owner-responsibility,
- Third-party-responsible work activities,
- Missing or inappropriate logic relationships,
- Failure to include resource logic,
- Network problems, such as:
    - Inappropriate use of lags,
    - Inappropriate use of Calendars
    - Dangling activities (activities that become open-ended upon progress),
- Cost loading problems,
- Resource loading problems.

2. The As-Built Portion of the Updated Schedule

The as-built portion of the updated schedule submission, the activities to the left of the data or status date, contains all the data for work that has already happened. The schedule information containing this work should be fairly straightforward since it is all actual data, actual start dates, actual finish dates, and actual progress on incomplete activities. However, the data is often not recorded accurately, sometimes due to the failure to record the information on a daily basis. When this happens, the as-built schedule data is in conflict with the data recorded in the daily field report, and it is important that the as-built schedule data is corrected for accuracy.

It is important to recognize that the as-built side of the schedule update documents the only true performance; this is the source of delays and gains, while the as-planned side of the update is a plan to achieve something, either mitigation of delays, revisions to the planned implementation, or additional activities. These attempts to mitigate or revise do not constitute actual performance, merely the plan, and the proof that the plan works will not show up until the following or a successor update when it shows up in the as-built side as performance.

Field documentation of actual events and effort is a vital part of the update and update review process. There is a wide variety of documentation needed to minimize claims and to protect the Owner from the consequences of a poor devised schedule.

The final part of this process includes extensive claims avoidance scheduling efforts on the part of the CM or Owner to determine the extent of liability on the part of the Owner. Considering that at this point, the Contractor may have supplied a schedule that cannot be approved, that failure ramps up the need for independent verification to determine what happened.

Within the scheduling and schedule review process, careful identification of major discrepancies in the schedule is an important step in getting better, approvable schedules. If the as-built portion of the schedule attempts to record a false history of the project, it should be challenged and revised to be accurate. This part of the schedule should provide actual data and support any forensic analysis needs later in the project.

E. Approval or Non-Approval

1. As-Planned or Baseline Schedule Approval

It is in the best interest of any project for the Contractor to submit and gain the Owner's approval of an as-planned (initial baseline) schedule as early as possible. The submission by the Contractor ensures early project planning, and the Owner's review and approval allows a sharing of expectations between both parties. So long as the Owner's management carefully studies the schedule and provides input to the Contractor regarding expectations and its understanding, the schedule submission, review and approval process becomes a key ingredient to the project team success. This process is further discussed in a recent paper co-authored by Carson[12].

In addition to promoting early dialogue between the Owner and Contractor about schedule expectations, challenges and assumptions, the as-planned schedule submission becomes important baseline documentation through which the parties can resolve later disputes.

[12] "Ramifications of Owner's Baseline Schedule Approval Decisions", Carson and Napuri, 2020 AACE International Technical Paper, PS-3428, AACE, Morgantown, WV, 2020.

2. Updated Schedule Approval

It is also in the Contractor's best interest to gain written approval from the Owner for the updated schedule submission. Importantly, if the Contractor fails to gain schedule approval, there is no approved basis from which to measure delays or disruption. The Owner has not accepted any responsibility for work requirements of it or its separate contractors, and the likelihood of proving entitlement to time extensions is reduced. There is also a reduced basis for proving Owner-caused delays or disruption requiring a significantly higher level of contemporaneous documentation.

Submission and approval of schedule updates is important to reducing potential disputes. Submission and review of schedule updates promotes continued dialogue about the status of the project progress and the influences impacting that schedule. This continued dialogue contributes to project success through fewer disagreements. When the Owner provides schedule review comments and the contract requires the Contractor to revise the schedule based on the Owner's comments, the resultant schedule will be a better product in a much stronger position for use in analysis.

3. Revision vs. Maintenance

A quandary for the Owner and the Contractor is when or whether it is necessary and appropriate to thoroughly review the updated schedule just as was done during the initial baseline schedule submission. When changes to the plan are significant enough that it could impact actions or services supplied by the Owner or Owner's agents, it is important that the Owner has the opportunity to review the schedule and provide feedback. This process could result in direction from the Owner to modify the schedule update to prevent violation of the Owner's requirements or overloading the Owner's resources.

If the parties do not choose to overhaul the schedule mid-project, the parties will continue to update the schedule, and if necessary, provide schedule maintenance or schedule revisions. The difference between those two concepts is important to understand.

The Contractor generally has the right to make minor modifications to the schedule. As long as those modifications do not impact the Owner's responsibilities, resources, or the contractual requirements, the Contractor may incorporate those modifications into the schedule without Owner approval. This process of minor modifications is generally called "schedule maintenance."[13]

However, when the modifications to the schedule affect Owner responsibilities or resources, or violate contractual requirements, those modifications become subject to the approval process. Only the Owner holds the final authority as to what modifications are acceptable. A schedule update that does make significant modifications and affects Owner responsibilities, resources, or contractual needs, is generally called a "schedule revision."

4. Schedule Revision Approval

When there is a significant change in the Contractor's means and methods, this constitutes a need for a formal revision to the schedule. The revisions may or may not be associated with a schedule update but they should require review and approval by the Owner as well.

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[13] "CPM Scheduling for Construction – Best Practices and Guideline" book, Carson, Oakander, Relyea, Section 4, "Schedule Maintenance" , PMI, 2013

Adjustments and revisions to the project schedule must be made in a timely manner to ensure that the project continuously and accurately addresses work that is either added or deleted and that sequence of work and means and methods match the current plan. Adjustments or revisions to the project schedule can and should be made when: (1) activities are inserted into the project schedule that represent new work added via an executed change order, (2) activities are deleted by means of a properly executed change order, or (3) activities' durations and network logic changes to represent changes in the sequencing of the work or means and methods. Adjustments or revisions to the schedule should be made in these situations to match the current plan to complete the project. It is important that the party making the adjustment to the schedule clearly describe both the change made and the reason for the revision. This transparency ensures understanding by all parties when revisions are made to the project schedule.

If the schedule contains exposure to the risks discussed earlier, then the CM or Owner's agent must take serious steps to protect the Owner's interests. This will prevent a situation where the Contractor can assert Owner liability and claim excessive damages where the records are not clear enough to refute that assertion. This will often happen when the Contractor refuses to revise the schedule to address an item on the deficiency list. The costs to resolve these types of disputes, when there is no approved or appropriate schedule on the project, will be considerably higher than necessary. This is often because the claims are very large and poorly documented, sometimes in an effort to provide negotiation opportunities. This means that taking additional steps to document and protect the schedule is worth the effort and costs.

5. Dealing with an Update That Cannot Be Approved

When a schedule submission carries too many risks to the Owner, it may not be in the Owner's best interest to approve the schedule, but rather to disapprove and provide comments describing corrective action necessary to qualify for approval. These comments would normally be shown in a deficiency list of issues that, if corrected, would allow the Owner to approve the schedule update. The deficiencies do not allow the CPM network and the schedule to act properly as the basis or benchmark for analysis, and will create false conclusions when used in delay analysis. If the Contractor refuses to correct the deficiencies, assuming that they are significant deficiencies, then the Owner must take some steps to protect the project from the inappropriate or misleading schedule submissions.

One approach that allows for continued analysis of the schedule is to create a series of schedules in which the deficiency list comments are used to revise the Contractor's schedule update. This generates a series of options, or "approvable schedules" for the Contractor to consider. Then analysis can be performed on these schedules for predictions of completion, delays, and recovery needs.

As these approvable schedules are created, it is useful to provide them to the Contractor, as they will demonstrate how much more closely the proposed options align with the as-built condition of the schedule than the unapproved submission. The goal of this exercise is to convince the Contractor that the approvable schedules better represent the means and methods of the plan and should become the official schedule update.

If this process is unsuccessful, and the project is operating without an approved schedule, additional monitoring and documentation of the completed work is required to ensure that there is detailed and validated history of the project. If the as-built schedule is maintained appropriately, the project is protected from a false history, and the as-built portion can be used in analysis. With the as-built, and the “approvable schedules,” it is possible to determine the Critical and Near-Critical Path and determine what the driving activities and which subsequent issues drove the previous update completion date.

F. Using the Schedule as a Management Tool

1. Level of Detail

Establishing the level of detail to require in a project schedule is one of the most important decisions in the development of a project. Preliminary evaluation of the appropriate level of detail occurs during schedule design, but must be revisited as development begins. There are a number of factors to consider when establishing the appropriate level of detail:

- The nature, size and complexity of the project.
- Too many activities may inaccurately reflect intricacies and interdependencies between the activities. This can result in redundant logic.
- Too few activities will require use of SS and FS lagged activities, making it harder to analyze. This can result in an inability to use the schedule for work planning and monitoring as well as not provide an adequate basis for analysis of performance, changes, and completion.
- High level of detail will make updates more time consuming.
- High level of detail will allow better monitoring & updating.
- High level of detail allows better monitoring of individual trade Contractors.
- Need enough detail to avoid incomplete activities waiting on others to progress.

The level of detail is best determined by breaking the project down into appropriate stages, where each stage may progress independently from other stages. Consideration must also be given to how progress will actually occur, so that areas with similar rates of progress can be grouped and updated together without reducing the accuracy of the updates.

The approach used to develop the schedule also affects the level of detail. Bottom-up approaches, while familiar to most trade workers, will often generate too much or uneven detail. This can be due to starting with the most detailed activities and either running out of time to complete. Or, familiarity with certain trades may increase the level of detail for those trades, and less detail for other, less familiar trades. Top-down approaches will often result in too little detail, sometimes with activities that include scopes of work that are attributed to multiple responsible parties, making it very difficult to assess entitlement and responsibility. Blended approaches often offer the most efficient and practical results, such as developing a top-down summary schedule followed by bottom-up development of the work scope aligned to the summary activities. This does allow for a more evenly developed schedule and is compatible with a WBS organization.

An example of the risk of too little detail in a schedule is using a few large duration activities to schedule wall construction in a building. These activities would include all the interior wall finishes in offices, multi-function rooms, conference rooms, and corridors, requiring an assessment to be made during updates as to the completion level of the activities. Often in a building, the corridors are the location for most main utility runs and the primary heavy traffic zone during construction. This means that the corridors will not progress at the same rate as the other offices and rooms, so when those offices are mostly complete, the corridors might not even be started. This could leave the interior wall finishes activities updated at 95% complete for long periods of time after the offices are complete only to accommodate the incomplete corridors. The results of this type of detail issue include increased numbers of activities that are scheduled out-of-sequence with each update, inability to analyze delays, and poor ability to predict completion. The problem worsens when the schedule is cost-loaded for invoicing.

The frequency of required updates will often dictate the level of detail. If monthly updates are required, a highly detailed schedule will extremely time-consuming.

2. Maintenance

Maintaining the project schedule requires continuous effort to ensure the current schedule closely resembles the project's current scope, activity sequences, activity durations, as well as other parameters such as resources and costs. Periodic review of the project schedule and input of activity progress is termed "updating." This process includes determining the current "status" of the as-built condition of the schedule and providing analysis of trending and completion predictions, as well as resolution of any delays or disruptions. The schedule update is a record of past performance and a reasonably adjusted prediction of future performance. An important aspect of the update is to determine whether progress on the project is meeting expectations. If not, this process allows the project team to determine what actions are necessary, to meet the overall project objective. The schedule update benefits the entire project team and stakeholders by allowing remediation of adverse impacts quickly.

3. Short Interim or Look-Ahead Schedules

There is no debate that the schedule must be appropriate for management of the project, obtaining stakeholder buy-in, benchmarking for completion predictions and analysis of impacts to the schedule, and supporting effective communication. However, it must also be useful for the weekly and daily planning in the field. These weekly or daily planning schedules are "short duration interim planning" and are often referred to as something like the "three week look-ahead schedules."

There are two basic ways to accomplish this:

1) Develop the 'look-ahead schedule level' using the CPM schedule at an appropriate level of detail to manage the weekly production (Level 4)[14].
2) Halt development of the CPM schedule at a 'project control level' of detail, requiring alternative methods outside the CPM schedule be considered for the "project control or task list level" (Level 3)[15].

Developing the CPM schedule to the look-ahead schedule level requires sufficient detail in all trades to allow for day to day management of those trades. This is a typical and popular approach for Contractors who either self-perform multiple trades or who have a significant investment in the development and use of the schedule. Development of this level of schedule requires the initial

[14] AACE International Recommended Practice No. 37R-06, "Schedule Levels of Detail — As Applied In Engineering, Procurement and Construction," page 3.

[15] AACE International Recommended Practice No. 37R-06, "Schedule Levels of Detail — As Applied In Engineering, Procurement and Construction," page 3.

planning be done by the project management team in some type of schedule development or planning session. These schedule development sessions allow for detailed discussions about the construction means and methods as well as investigation into sequencing options in order to choose the appropriate modelling approach. Practically speaking, if the project management team does not have a comprehensive knowledge of the project documents and/or is not willing to commit to working out many project details well in advance of the construction, then a Level 5 schedule cannot be developed. However, if this schedule is developed, it can act as a very detailed and accurate road map for the project team throughout the project.

Developing the CPM schedule at a higher (lesser) level of detail and allowing a superintendent to produce short interim schedules outside of the project schedule is another viable method of project scheduling. The schedule is developed as an overview schedule, designed to provide enough detail for use in reporting, delay analysis and completion predictions. The superintendent only develops the daily detailed work schedule just ahead of the need to manage the work. Thus, this approach is more closely aligned to a rolling wave type of scheduling process. It is imperative that someone correlates the project schedule and the superintendent's more detailed schedule. There should be a clear traceability between the short interim schedules and the project updated schedules in order to properly analyze performance, delays, and responsibility for those delays. It is vital that these short interim schedules are included in the continuous project documentation for use in any future analysis needs as the higher level schedule updates will not convey the full story of performance and progress.

4. Integration of schedules and management software

Project management software is commonly called the Project Management Information System (PMIS). PMIS is any software tool used to monitor documentation for the project for all stakeholders. Since the schedule is a primary communication tool, the best way to ensure good communications is for the scheduling software to be integrated with the PMIS. When done properly, the PMIS can be the central location for the project management team to manage the project, and the scheduling tool will help keep the team focused on the critical and current needs of the project.

The PMIS can provide an online dashboard which captures scheduling information and summarizes that information to help all team members react timely. This dashboard addresses all of the daily issues requiring resolution, and with the schedule integration of the PMIS, the dashboard will promote issues as they become more critical.

5. Schedule Updates

On most projects, the baseline or as-planned schedule is adjusted to reflect the current project conditions at any given time. This periodic adjustment or revision is called updating the schedule. Schedule updates are typically provided on a frequency determined by the contract, and updates are most commonly required monthly. Contractors who use the schedule for day-to-day management often update their schedules on a weekly basis, which provides better monitoring and controls.

The frequency of the updates is part of the decision as to the level of detail to be used with a schedule. Accurate updating is vital to monitoring progress, analyzing and mitigating impacts, and to the accuracy of predicted completion of milestones such as Substantial Completion.

Just as there is no right or wrong baseline or as-planned schedule, there is no right or wrong update schedule. With many different ways to pursue and perform construction projects, no single schedule is the correct way to build the project. Therefore, project management simply needs to make sure that update schedules are reasonable, buildable, appropriate to the project contractual requirements and the field conditions.

a. As-Built Portion of Update

The work that is underway or completed during each update must be captured and recorded in the schedule. This consists generally of actual start dates, actual finish dates, and remaining durations of the work that is started but not finished. These three data points provide the results of progress in the schedule.

What these three data points do not provide is the actual history of how the project has been built to date. This history is determined by the logic and settings in the schedule software. A reasonable schedule update will show the history of the project accurately depicted in the schedule logic and settings. This is very important in the case of a dispute, delay, or disruption, where analysis is necessary using a forensic analysis technique. A false history shown by the activity names, actualized calendars, and logic relationships in the schedule will make it more difficult to resolve these types of issues. The process of recording and validating the as-built data is often called "statusing" the schedule, and is the first step in the Schedule Update process.

b. As-Planned Portion of Update

Once the as-built portion of the schedule is updated, the portion of the schedule that models the future work is called the as-planned portion. It is very important that this part of the schedule is reviewed each update period to ensure that it continues to model the plan that is envisioned by the project management team, and that it is supported by actual events. If this portion accurately models that field plan, the schedule can be relied upon as a reasonable and accurate basis for analysis and completion predictions.

This review of the as-planned portion of the schedule, along with the completed as-built portion, and any other data integration necessary to ensure the schedule models the plan to construct, is generally called the full Schedule Update process.

6. Determining the Benchmark for Analysis

In order for the baseline or as-planned schedule to provide a good benchmark for analysis, it is necessary that the schedule represents the construction plan in a reasonable and appropriate manner.

In order for the schedule to provide a good benchmark for analysis, it is necessary that the as-built portion is accurate and validated, the as-planned portion represents the plan, and the software settings support an accurate model. When this is done properly, the updated schedule can serve as the basis for analysis. These updates create a benchmark for the schedule. The analysis can be done for a variety of purposes, including analysis of delay or disruption, trending and general performance analysis for completion predictions.

It is important that there is also a formal process called "Benchmarking" that is used by some owners, particularly some federal government owners. This formal process is used to maintain a contractual vehicle using the cost loaded scheduled to keep track of the contractual time and cost status. When the baseline or as-planned schedule is formally approved, it is called the Benchmark schedule. During the project, if there is a time and/or cost change that is accepted, activities are added to that original no-progress baseline or as-planned schedule that modifies the schedule to reflect the contractual status. This is done numerous ways, sometimes with a single activity or a fragnet of activities that model the change, each cost loaded to reflect the change order amount. For the time extension, the activity or fragnet is logically connected and carries the appropriate duration so that it extends the original baseline schedule to match the new approved change order.

This "Re-Benchmarked" schedule still has no progress and does not represent the contemporaneous condition of the project since it was frozen at the time of initial submission and the added activity or activities to house change order time and cost do not represent the project plan. The Re-Benchmarked schedule is only a contract vehicle and cannot be used to provide any analysis. Any attempt to use this schedule for an analysis will result in the forensic schedule methodology commonly called an Impacted As-Planned method (MIP 3.6, Modeled / Additive / Single Base) and is subject to the considerations discussed in the Forensic Schedule Analysis Recommended Practice[16].

7. Monitoring

There are three main areas that must be monitored on a project to support timely completion: the Critical Path, the Near-Critical Path, and all the other activities (sometimes called the Non-Critical Path). The Critical Path must be monitored because those are the activities that could cause a direct delay and extend the project predicted completion. The Near-Critical Path must be monitored because those are the activities that could cause a mid-period Critical Path slip, or delay, and since they were not on the Critical Path at the beginning of the period, slippage of those activities is less likely to be noticed. The Non-Critical Path activities, or the mass activities in the schedule, must be monitored because those activities represent the work that, if not pursued and completed expeditiously, could easily stack at the end of the project and cause major delays and disruption from overloading of resources, of trades, and of spaces.

a. Critical and Near-Critical Path Analysis

Critical and Near-Critical Path analysis should take into account the progress of the previous period's activities that could cause delay, and those are typically the Critical and Near-Critical Path activities. The first step should include review of the previous update plan to see what happened to that plan. This is often revealing as it demonstrates whether the Contractor's planned means and methods were followed or not.

The next step in the analysis is a review of the effects on network revisions and other non-progress related modifications to the schedule. This will often point out changes to the Contractor's means and methods that were not described in the written narrative, which is essential to understanding the legitimacy of those modifications.

[16] AACE International Recommended Practice No. 29R-03, "Forensic Schedule Analysis," April 25, 2011, Revision.

This analysis will identify which activities created delays to the project schedule, and the extent of those delays. Further investigation and research is necessary to determine if there were multiple issues that contributed to a activity delay, such as a schedule activity of "Lay Masonry Wall" that was actually delayed by failure to deliver bearing plates that halted the masonry wall construction. Once those issues are identified, it is necessary to determine which issues were the cause of the impacted schedule activity, and if there is any concurrency in multiple driving issues. The driving issues can provide support for identification of responsibility for delay and subsequent liability for delay damages or costs.

The analysis should identify why the Critical and Near-Critical Path at the end of the period is different from that at the beginning of the period. This mid-period shift in the driving activities or issues is helpful in determining what caused the delays and who bears responsibility.

The combination of the effects of progress and those of network revisions results in a new Critical Path for the project. Schedule response recommendations take into account the implications of this new Critical Path, both from a construction and a contractual perspective.

b. Non-Critical Path (General Progress) Analysis

During routine schedule updates, the Total Float values will be reduced consistently, moving activities onto the Near-Critical Path and then ultimately onto the Critical Path. However, if there are any problems with the schedule sequencing and logic, durations, or other components such as lags and calendars, reductions in Total Float values may not serve to move the activities from Non-Critical to Critical enough to identify problems related to progress. Although reasonable progress on Critical and Near-Critical Path activities will help keep project on track, if the rest of the work doesn't progress at a reasonable rate, the project could suffer delay and disruption.

There are multiple methods to monitor and analyze these Non-Critical Path activities: Earned Value Management, Float Dissipation, Missed Start and Finish dates, Resource Analysis, and others. Each method has advantages and disadvantages, as discussed below.

Earned Value Management uses cost or resource loaded activities to monitor progress, and compares the actual stage of completion of those activities to what the baseline schedule shows should be the stage of completion at any given update. This comparison is used for immediate analysis, or can be the basis to project how the historical progress data would affect the project if that rate of progress should continue to the end of the project.

Float Dissipation monitors the rate at which Total Float is reduced with each update and compares that to the remaining time to determine if that rate of reduction will allow completion on time. It can also be useful for identifying where resources are moved to augment certain portions of the project and where they are lacking, allowing delays.

Monitoring of Missed Start and Finish Dates can be used as a measure for how the general work is being pursued and completed. If the activities are not completed at a reasonable rate, it will affect the amount of work that is remaining at any given time.

All of these techniques are useful in evaluating the progress of those activities that do not show up on the Critical or Near-Critical Path. When these Non-Critical Path activities are not completed as scheduled, they must be then added to the workload to be completed in the future. As these activities slip into the future, the increased concurrent activity workload will create situations where more and more crews and individual resources are required to complete the scope of work. It will also force similar trade work to stack and increase those trade resources, or force more trade work to work concurrently in less and less spaces. Slippage of this Non-Critical Path work will generally require too much work to be completed in more concurrent situations late in the project, and often is responsible for lowered efficiency, increased costs, lowered quality, and delays to the project completion.

c. Trending Analysis

Historical progress data is useful to identify trends in how work is accomplished or lack of progress. Work patterns for various trades or locations are often established during the project. Historical data will reveal those patterns.

Establishing trends provides some benefit in predicting how the project will continue to operate if those trends do not change. An example of trend analysis is identifying a four day delay on the fifth floor of a fifteen story mid-rise building and recognizing that the delay is due to the work pattern. Without this analysis, this pattern is likely to continue on the next ten floors. A simple monthly analysis would identify a four day delay, but the trend analysis would identify a potential 40 day delay. Trending analysis helps identify patterns of work that need to be evaluated and mitigated. This analysis is done by review of historical data, using the as-built portion of the schedule. Review of how the various trades progress compared to the original plan yields some trends that might affect the project.

One method of trending analysis is comparing the Actual Duration for each activity with the Original Duration of that same activity, then clustering those activities by trade, by floor, by stage, or other grouping. At one time there was a software package that produced this particular comparison, called "Tipper" or the Total Performance Ratio (TPR). TPR divided the Actual Duration by the Original Duration. A value of more than 1.0 indicated an overrun in the performance time. If a particular trade had overruns, one technique was to identify that overrun, such as 1.7, and run a simulation by increasing all future durations for that trade by that factor. The resulting schedule would show the effect if the lowered performance continued.

Trending analysis is very important as a risk avoidance effort, and helps place the focus on weaknesses in the project that need to be monitored or resolved. Some of the full list of trending metrics that are valuable to collect for comparison purposes include:

1. Percentage of activities on the Critical Path – linear different from non-linear projects
2. Percentage activities on Critical Path compared to remaining as-planned activities
3. Percentage activities per life-cycle stage/phase
4. Percentage of project duration for major milestones – foundations complete, structure complete, dry-in, rough-ins complete, commissioning started (comparing to values from USACE milestone spreadsheet)
5. Distribution of activity counts by trade
6. Percentage of activity cost by division/section
7. Ratio of number of activity relationships to activity count
8. Ratio of count of activities to project value
9. Ratio of count of activities to project duration
10. Ratio of peak crew count to total project crew count (per trade)

11. Percentage of activities completed compared to total count of activities
12. Percentage of activities completed compared to remaining incomplete count
13. Total Float dissipation proportions (float/duration)
14. Ratio of activities actually started compared to planned to start (current period)
15. Ratio of activities actually completed compared to planned to complete (current period)
16. Tipper – ratio of actual durations compared to original durations (TPR report)
17. Plotted banana curves (Early dates, average dates, late dates)
18. EVMS
    a. Performance metrics: CPI, CV, SPI, SV, Budget Variance, Budget at Completion
    b. Prediction metrics: EAC, TCPI (To-Complete Performance Index)
19. Earned Schedule metrics: SPI(t), SV(t), TSPI (To-Complete Schedule Performance Indicator)

d. Risk Monitoring

Any risks that were accepted at the outset of the project must be closely monitored during the project. This is best accomplished by tying those risks to the appropriate activities, and as the schedule updates are advanced, activities that are carrying accepted risks move onto the short interim planning schedule. This permits additional scrutiny for those activities in light of the originally identified risks. If the accepted risks show up as problematic, they can be analyzed and mitigated timely.

8. Improvements in Schedule Performance

There are a number of ways that the schedule performance is improved, which is often vital in recovering performance losses. It is important to identify these improvements and be ready to assign responsibility for them.

a. Unacknowledged Recovery

Sometimes the project prediction of completion improves during the schedule update and no one analyzes the changes, so there is no acknowledgement of the time recovery. This does not mean that there is no responsibility for the time improvement that might be later identified and assigned in the case of disputes or assessment of delay damages.

Generally gains in time during schedule updates results in additional Total Float gain to the project. If the contract is silent on Ownership of float, the gain in float is available to the project, for use by the first need. It is important that analysis does identify the gains and any associated responsibility in case there is a need to assign it at some future date.

It is also important to recognize that often recovery efforts rely upon future efforts in the schedule, which is not the most desirable way of recovery. The original plan was conceived with certain durations, sequences, phases and schedule settings, and any effort to change those in the updates should be reviewed carefully to ensure that the planned means and methods are not breached unintentionally. Considering that the predicted completion date is a function of all of these issues, it is possible to manipulate the components in order to regain time and show a predicted completion that meets the contract requirement. Those manipulations may or may not be realistic and could put the future performance plan in jeopardy.

If the unacknowledged recovery is due to these modifications to the as-planned portion of the schedule, it is very important that a careful review of that portion is performed to ensure that it is still a reasonable and appropriate approach to completing the project.

b. Absorption of Delay

Delays fall into one of two categories in schedule updates: those that are predicted and those that have already been absorbed into the schedule. For predicted delays, it is most appropriate to perform a prospective Time Impact Analysis (TIA) to assess the full impact of the delays. When a delay has already been absorbed into the project, then it is no longer appropriate to perform a prospective analysis, and it is important that the delay is analyzed by the appropriate Forensic Schedule Analysis methodology[17].

c. Recovery, Mitigation or Acceleration

When the project gains time or suffers delays that are offset by improvements to the schedule performance, the improvements could be due to recovery or mitigation of the delays or acceleration of the project.

Recovery does not indicate the responsibility for the gains in time, so it could mean the Contractor recovered or the Owner took actions that recovered time. Recovery on the part of the Contractor could be as simple as making a decision to work out of sequence or implement a parallel Critical Path on the project, and those actions could be shown in the schedule by logic revisions that do not require any additional resources and do not cost anything to implement. A common term used for re-sequencing and creating parallel Critical Paths is "Fast Tracking." These recovery efforts generally would not create any entitlement for additional costs, even if the lost time was the responsibility of the Owner.

If the delays are the responsibility of the Contractor, or a Force Majeure event, the recovery effort that the Contractor implements could be mitigation of the Contractor's delays and not eligible for cost reimbursement. Recovery could also be implemented to mitigate Owner-caused delays and result in entitlement for an excusable and delay compensable extension. Mitigation is a responsibility-neutral term, not indicating Owner or Contractor responsibility for the original delays.

However, if the recovery requires shortening the schedule and results in additional costs in resources, equipment, or materials, the effort is acceleration. Acceleration generally is an Owner-requested action that entitles the Contractor to compensation. A common term for shortening the schedule duration by additional resources is often called "Crashing."[18]

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[17] AACE International Recommended Practice No. 29R-03, "Forensic Schedule Analysis", April 25, 2011 Revision.

[18] Project Management Institute (PMI) Guide to the Project Management Body of Knowledge (PMBOK® Guide), 5th Edition, Chapter 6, Section 6.6.2.7, "Schedule Compression."

9. Claims Avoidance

An important benefit of schedule updates is that the review process mitigates the opportunity for claims. The review process provides opportunities for timely resolution of all outstanding issues. It is axiomatic that unresolved and unaddressed issues are likely to continue to grow into disputes. Since the schedule is the primary claims analysis document, it is important that it is reviewed and validated with each update, and that at all times, the schedule is an appropriate and reasonable model of the means and methods to complete the project.

Changes that result in time extensions should be analyzed and resolved timely so that they do not place the schedule in a position that it no longer represents the plan. Failure to approve appropriate extension of time requests fosters a myriad of potential problems, including constructive acceleration, see Section 5c.

There are a number of steps that should be taken during the update schedule review to provide claims avoidance opportunities. Recognizing types of delays and the situations that result in those delays can improve the process to avoid claims situations. As noted in the Scheduling Claims Protection Methods Recommended Practice: *"The accuracy and completeness of the project schedule is important to the early and successful resolution of the schedule delay claim issues. When the schedule is properly developed, accurately maintained and supported by the project documentation it is a vital element for successfully resolving delay claims."*[19]

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[19] Project Management Institute (PMI) Guide to the Project Management Body of Knowledge (PMBOK® Guide), 5th Edition, Chapter 6, Section 6.6.2.7, "Schedule Compression."

Instructions for submitting papers to PGCAR

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