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."[1] 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

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

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.

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[2].

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

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

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, 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[3]. 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.

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

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.

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*[4]*.*

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,

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

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 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[5]. 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.

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[5] 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."

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 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."[6] 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,

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

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.

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[7].

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

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

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.

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[8].

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.

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

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 "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[9], 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[10].

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.

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

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

- 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.
- 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[11].

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.

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."[12]

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

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

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

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.

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)[13].

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

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)[14].

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 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.

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

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[15].

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.

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

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.

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[16].

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

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

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."[17]

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."*[18]

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[17] 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."

[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."