EFFECTIVE CONSTRUCTION SCHEDULE MANAGEMENT:

CONSTRUCTION PROJECT MONITORING WITH

PROJECT PERFORMANCE INDICATORS &

THE PROJECT STATUS REPORT

by

CHISTOPHER MICHAEL TOTIN

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ABSTRACT

EFFECTIVE CONSTRUCTION SCHEDULE MANAGEMENT:

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Christopher Michael Totin, M.S.

The University of Texas at Arlington, 2012

Supervising Professor: Mohammad Najafi

A thorough review of construction and engineering literature was conducted to discover and organize current best practices and standards for the purpose of monitoring a construction project. The status of a construction project is a measurement of its progress and performance in terms of time, cost, and scope.   Awareness of a construction project's status improves decision-making on the part of owners, engineers, contractors, and other project stakeholders. Project Performance Indicators (PPI) are metrics generated by construction project schedules that define a project's status. Project personnel must monitor critical schedule and cost data, or PPI, in order to maintain control of the project. This thesis describes the methods of extracting and analyzing PPI as well as scheduling specification language supporting the ability to contractually obtain PPI. To that end, a Project Status Report (PSR) is developed to organize and display PPI for the purpose of documenting, reviewing, and analyzing PPI. In its entirety, the purpose of this thesis is to serve as a guideline for developing a construction project monitoring program in efforts to improve the rate of successful construction projects.

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CHAPTER 1

INTRODUCTION

<u>1.1 Introduction to Schedule Management</u>

Construction project schedules are vastly dynamic, some of which may contain thousands of activities in multiple states (i.e., planned, in-progress, and finished) with unique sets of data assigned to each activity. To keep track of a project as it relates to cost and time, the project team must actively monitor these data sets, which are indicative of a project's progress and performance, or status. In essence, project monitoring and control is the process of measuring planned project performance against actual performance, while establishing the state of the project as it relates to physical, financial, and temporal completion. "Based on project performance measurement, the project team can activate a project control process to ameliorate any issues and return the project more in line with its scheduled course," thus combating project failure (Ritz 1994).

Cost and schedule are among the most influential factors in evaluating project success or failure, as they unveil whether a project will finish on time and within budget. Project personnel must control cost and schedule from the onset through the completion of the project to effectively monitor, forecast, and measure the performance of a project. "Activating any adjustment late into the project is often ineffective and expensive; the later the corrective action, the less the ability of influencing the project outcomes" (Sterman 1992; Nepal 2006). Additionally, performance measurement allows project team members to create accurate time and cost forecasts, mitigate construction-related issues, and take both preemptive and corrective action. Failure to effectively monitor the project's status may result in time and cost overruns, thus jeopardizing the achievement of contract milestones.

Construction schedules vary in degree of efficacy as tools to plan and manage construction activities. However, a well-developed construction schedule produces valuable metrics, or Project Performance Indicators (PPI), that can be used to determine the status of a project. Metrics are quantitative or qualitative, verifiable measurements that "capture performance in terms of how something is being done relative to a standard" (Christensen 2000). These metrics can be analyzed to determine a project's status, while aligning with stakeholder's expectations to define what is considered acceptable and unacceptable performance.

By detailing methods of extracting, analyzing, and effectively reporting PPI, this thesis can be utilized as a guideline for developing a construction monitoring program. Additionally, scheduling specification language is examined to ensure PPI is contractually obtainable from a construction schedule. The result of this research is an executive dashboard called the Project Status Report, a concise PPI reporting mechanism to be featured as part of a construction project monitoring program.

1.2 Thesis Objective

By combining many methods of construction project control and effectively reporting the resulting PPI, the objective of this research is to assist in the development of a systematic approach to monitoring a construction project's schedule and cost. As such, the breadth of this thesis is to investigate principles of project monitoring and control, analysis of PPI, contract language associated with PPI, and the methods of reporting PPI. The result of this research yields a Project Status Report that may be utilized by project teams to gain insight on the progress and performance of construction projects.

1.3 Methodology

This objective is accomplished by conducting a thorough review of industry literature to determine the current best practices and standards available for construction project monitoring.

Furthermore, a review of schedule metrics utilized by industry leaders in schedule management is conducted for the purpose of determining the most informative PPI. These PPI are derived and analyzed in order to improve one's ability to implement the proposed project monitoring program. Additional research is performed to discover technical reporting criteria and information design for the purpose of creating the Project Status Report.

1.4 Thesis Scope

This thesis explores PPI with respect to contract specifications, quantitative PPI derivation, and qualitative processes of construction project monitoring. The focal point of this research is to discover the most important PPI contained within a construction schedule. Additionally, this thesis outlines contract language that promotes the inclusion and analysis of PPI in the schedule. Finally, the result of this research is an illustrative representation of PPI, the Project Status Report, which can be utilized by construction professionals across industry lines. As such, it is a turn-key document that can be utilized to develop a construction project monitoring program.

1.5 Research Needs

There are far too many projects that "fail." Over the past 70 years, it is estimated that 50% of roadway projects experienced cost and/or scheduling inaccuracies greater than ±20% (Flyvberg 2006). Furthermore, cost overruns exceeding 25% are common in the construction industry (Thelen and Priest 2004). Though much research has been conducted on the various components of monitoring construction projects, the construction industry has yet to adopt a uniform set of standards for cost and schedule control.

The current approach to assessing a project's performance has the following limitation:

(1) the comparison is only as good as the estimated values for cost and schedule; (2)

there is no certainty or prediction of achieving a successful outcome; and (3) normally

only a few key variables are monitored (Jaselskis et al. 1997)*.*

This is, in large part, due to the "tailored methods for decomposing the complex scope of work into work items and tasks with regard to cost and schedule tracking" (De Marco et al. 2009). The complex nature of project monitoring and control has limited the usage of effective project monitoring programs.

However, "an enterprise should apply some form of cost-schedule control to track project performance relative to the planned time and money expenditures linked to planned achievements" (Grady 2010). Many best practices have recently been developed by organizations such as the Project Management Institute (PMI) and the AACE International, formerly known as the Association for the Advancement of Cost Engineering (AACE). Furthermore, advancements in technology, from faster computer processors to software tools, are delivering faster access to more accurate data. As such, it is necessary for continued research towards an integrated approach to cost and schedule control under the pretense of current construction legal precedence and best practices, available technology, and high project failure rates.

1.6 Expected Outcome and Limitations

The intent of this research is to produce a series of data for the development of a construction progress and performance monitoring tool, the Project Status Report, which may be utilized across the industry to increase the number of successful projects. Thus, the hypothesis of this thesis is that by utilizing the Project Status Report to monitor construction projects, project personnel can make smarter project-related decisions thus increasing project success rates. In order to prove this hypothesis, the Project Status Report must be utilized on a number of projects. Upon implementation, project success and failure rates are monitored to determine whether the Project Status Report is an effective means of improving the project

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success rate. Alternatively, the Project Status Report can be introduced to various engineering and construction agencies. If members of the construction industry determine that the Project Status Report is more effective and efficient in delivering pertinent project information, then this research has served its purpose. To date, several industry professional have provided positive feedback indicating that the Project Status Report would be an efficient and effective means of monitoring a construction project.

1.7 Background and Literature Review

A thorough review of technical journals, books, white papers, and industry standards, as well as person-to-person interviews have been conducted for the purpose of understanding how to effectively monitor a construction project. Much qualitative and quantitative research has been conducted (Marrella 1973, Kim 2000, Vargas 2003) that suggests that monitoring schedule metrics is an effective project management solution. Additionally, evolving Earned Value Management practices have improved the predictability of project costs and schedule milestones (Anbari 2003, Lipke 2003, Jacob 2006, Vandevoorde and Vanhoucke 2006). Furthermore, it is commonly accepted that "real-time knowledge" of cost and schedule performance indicators, resources utilization, and schedule compliance are crucial factors affecting the ability to make sound project-related decisions (Sterman 1992, Nepal 2006, Vanhoucke 2009, Patterson 2010). This complex set of data must then be effectively reported to project stakeholders in order to improve the accuracy and timeliness of decision making.

1.8 Chapter 1 Summary

Chapter 1 introduced the topics to be covered in this thesis which include the methods of extracting and analyzing Project Performance Indicators (PPI), schedule specification language associated with PPI, and the means of reporting PPI using the Project Status Report. Additionally, this chapter provided an overview of the thesis objectives, methodology, scope, research needs, outcomes and limitations, as well as background and literature review.

CHAPTER 2

PROJECT PERFORMANCE INDICATORS: EARNED VALUE

2.1 Introduction to Earned Value Management

Earned Value Management (EVM) was developed in the 1960's by the United States Department of Defense. EVM is used to measure and report the performance and progress of a project by "integrating three critical elements of project management: scope, time, and cost management" (Vanhoucke 2009). In doing so, EVM assesses the physical amount of work completed in relation to the time and cost effort utilized to complete the work. It also aids in the evaluation and control of project risk by expressing progress in monetary terms thus revealing exposure. In all, this methodology generates valuable data that project personnel can utilize to detect project issues or to take advantage of opportunities.

EVM utilizes Earned Value (EV) data to measure and analyze project progress and performance, whereby budget dollars are earned as scheduled work is performed. EVM answers the questions:

- What did one receive for what one spent?

- What is the difference between actual and budgeted costs?

- Is the project on schedule, behind schedule, or ahead of schedule?

- What is the expected remaining cost and duration of the project?

In other words:

Earned Value Management Systems have been setup to deal with the complex task of controlling and adjusting the baseline project schedule during execution, taking into account project scope, timed delivery and total project budget. It is a generally accepted management system that integrates cost, schedule, and technical

performance and allows the calculation of cost and schedule variances, performance

indices, and forecasts of project cost and schedule duration (Vanhoucke 2009).

2.1.1. History of Project Monitoring

Historically, project personnel have utilized a two-variable approach to construction project monitoring, comparing actual cost to planned cost. To clarify, actual cost is the amount of money spent to complete the activity, while planned cost is the amount of money that is estimated to complete the activity. This method falls short in that it fails to measure the planned cost of the completed work, which is known as the budgeted cost of work performed or earned value. In one instance, actual costs may appear to be less than planned cost, which signifies the project is under budget, as detailed in Figure 2.1. However, "since the actual performance efficiency is not as precise as the initial assumption used in the project planning phase, the actual cost incurred is not a true reflection of the actual accomplishment" (Chen 2008). This comparison does not account for the actual amount of work accomplished, thus the project is not necessarily 50% physically complete once 50% of the budget is spent. An additional variable, Earned Value, must be evaluated to gauge actual accomplishment of scheduled work and its associated cost.
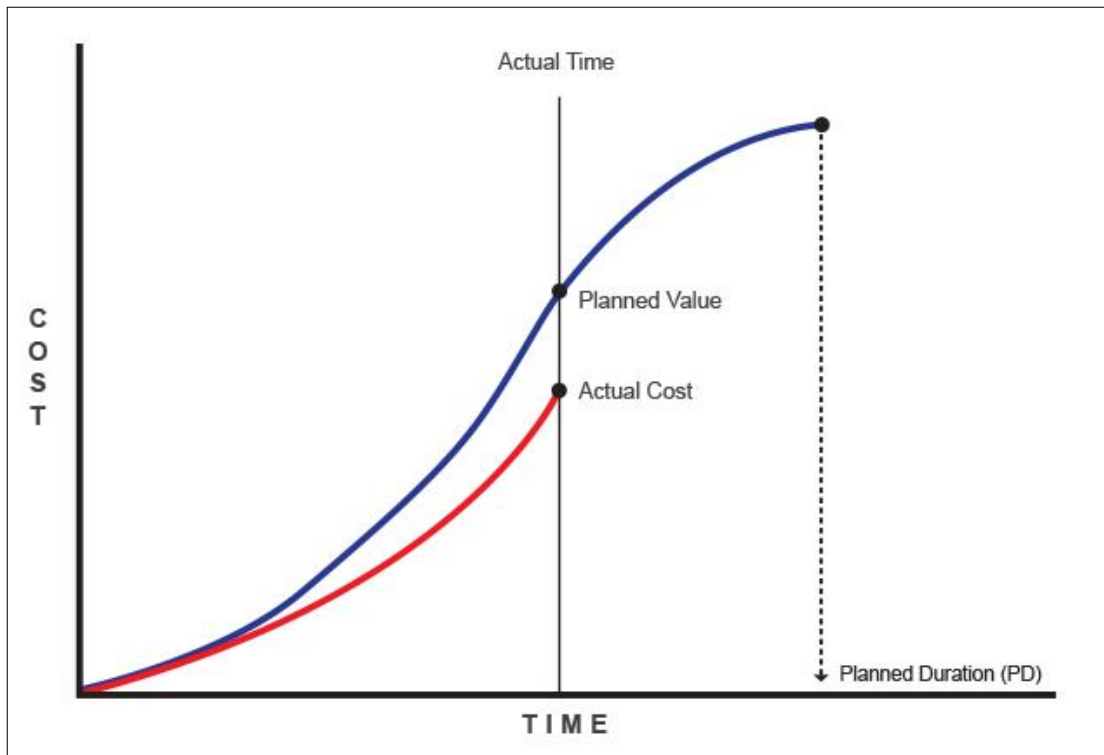
Figure 2.1: Historical Cost Management (Wilkens 1999)

2.2 Traditional Earned Value Management

An effective Earned Value Management System (EVMS) utilizes a three-variable approach: planned, actual, and earned (see Figure 2.2). The earned variable, or the Budgeted Cost of Work Performed, is the planned budget of those activities that have been completed by the date of analysis. This variable is crucial in determining the deviation between current (or actual) and planned performance. Under this three-variable system, organized components of the project's schedule, cost estimate, and scope of work enable a more reliable determination of the project's forecasted costs and, more recently, forecasted duration of the project (Warhoe 2004).

Although originally developed for cost management, recent research points to an increased interest in utilizing Earned Value Management (EVM) for predicting the total project duration (Vanhoucke 2009). Additionally, much EVM research is currently being conducted to

improve the accuracy of EMV and optimize its implementation, as it is considered "one of the most under-used, yet effective cost management tools available for performance measurement" (Flemming 1994). By producing both cost and schedule PPI, EVMS alone makes for a powerful monitoring tool.
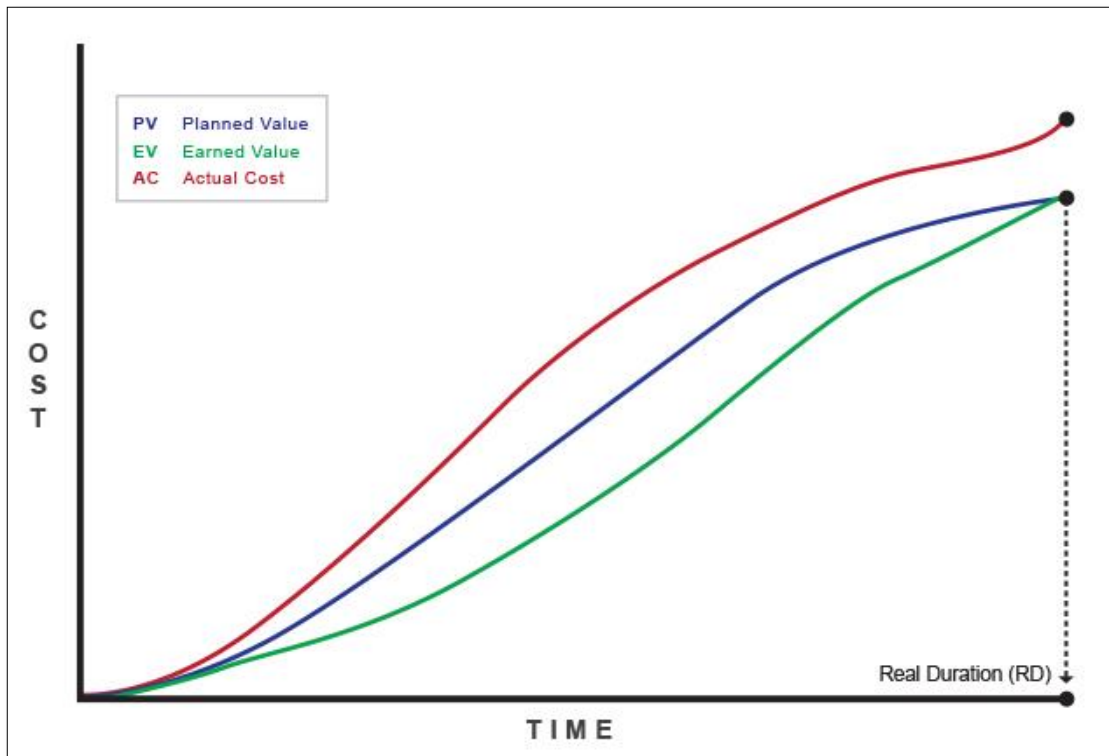
Figure 2.2: Graphical Representation of Earned Value: The S-Curve

2.2.1. Key Elements of the Earned Value Management System

The following EV elements are key contributors in the development of PPI:

- *Planned Duration (PD)*

    PD is the estimated duration of time to complete the project. This amount of time is determined by assessing the project duration as defined by the baseline schedule.

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- *Real Duration (RD)*

  RD is the amount of time taken to complete the project, which is determined upon completion of the project. In most cases, RD is the number of days between the actual project start date (e.g., Notice to Proceed) and actual project finish date (e.g., Final Acceptance).

- *Actual Time (AT) or Actual Duration (AD)*

  AT is synonymous with AD, and it is the amount of time that has passed during the course of the project (i.e., AD = 1, 2, …, RD). AT is calculated by subtracting the date of analysis from the actual project start date.

- *Budget at Completion (BAC) or Planned Value (PV) or Budgeted Cost of Work Scheduled (BCWS)*

  BAC is the estimated cost to complete the project, which represents the collective budgets of scheduled or planned activities. BAC is synonymous with PV and BCWS. It is a time-phased budget baseline generated from the baseline schedule, which details how much money is expected to be earned throughout the entire project. Most scheduling software tabulates the BAC, and it is viewed by displaying a cost column. The BAC should exactly match the value of the construction contract.

- *Budgeted Cost of Work Performed (BCWP) or Earned Vale (EV)*

  BCWP represents the planned, estimated, or scheduled cost of activities that are complete. BCWP is also known as the earned value variable. It is a function of time, cost, and work, which provides an integral link between the project budget and schedule (McConnell 1984). The difference between BCWS and BCWP is that BCWS represents the planned budget of activities that are scheduled or have not been performed, whereas BCWP represents the planned budget of activities that are complete or have been performed.

- *Actual Cost of Work Performed (ACWP) or Actual Cost (AC)*

  ACWP is synonymous with AC, and it represents the cumulative actual cost incurred

  by completed activities at a given point in time AT.

2.2.2. Building an Earned Value Management System

The core of the EVMS is the s-curve. The s-curve provides project personnel with a graphical representation of key project cost and schedule data. In order to construct an accurate s-curve, there are a number of tasks that must be completed with much diligence. The more detail applied to these tasks, the more accurate the s-curve produced. The following tasks are required to produce accurate EV PPI.

1.   *Plan the work.*

   Planning is perhaps the most cost-effective means of achieving project success. "It is also the most important, [as] it requires an intimate knowledge of construction methods combined with the ability to visualize discrete work elements and to establish their mutual interdependencies" (Sears 2008). The accuracy of progress monitoring and the resulting PPI are directly related to the diligence undertaken during the planning phase. Project site visits, resource availability and subcontracting analysis, construction sequencing, cost estimating, and production analysis are among the many planning activities.

2.   *Create the Work Breakdown Structure (WBS).*

   The WBS is a high-level, organizational tool that subdivides project activities into manageable work elements (e.g., area of work, type of work, divisions, location, person, firm, etc.). It can also be used as a planning tool to help identify activities prior to developing the schedule and organize activities once the schedule is built. Figure 2.3 illustrates a WBS created in Primavera Project Management in which activities are

organized into four areas. Each activity is assigned a unique WBS code (e.g., Ifajan Pipe Laying Area 1, Ifajan Pipe Laying Area 1.Excavation, etc.), which builds intelligence into the activity. This intelligence can be used for various project monitoring tasks including but not limited to activity grouping, resource monitoring, and cost reporting.
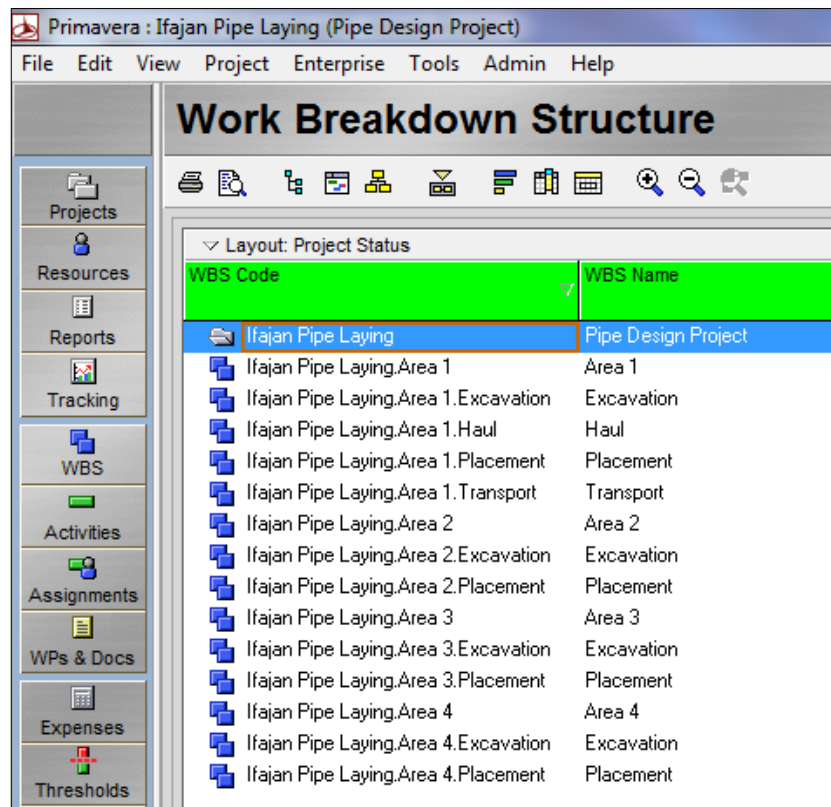
Figure 2.3: Work Breakdown Structure in Primavera P6.2

3.   *Indentify and schedule activities that encompass the entire project's scope of work.*

There is ongoing debate regarding the level of detail required by a schedule because there is no one standard set of scheduling specifications. As such, each project may have unique scheduling specifications. Among all schedules, however, it is expected that project's entire scope of work be represented by activities in the schedule. It is also

good scheduling practice to utilize logical relationships (e.g., finish-start, start-start, etc.) to link all activities. This logic establishes the planned construction sequence which, in turn, determines the planned project duration. Additionally, each activity should be assigned or output the following data to in order to maximize the effectiveness of PPI:

- Activity ID

- Activity Description

- Original Duration

- Physical % Complete

- Early Start/Early Finish (obtained from forward pass)

- Late Start/Late Finish (obtained from backward pass)

- Total Float

4.   *Allocate resources for each activity.*

Assigning materials, labor, and/or equipment to each activity is referred to as "resource-loading" the schedule. "A resource-loaded schedule clearly indicates to all parties the fundamental interdependencies between activities and resources under which the contractor will be performing construction" (Sears 2008). Resources constrain the project schedule, as limited resources tend to drive the construction schedule. A schedule with no resource constraints may imply the availability of unlimited resources which may, in turn, imply that "the contractor has the flexibility to apply all necessary resources to a project change without incurring additional costs" (Sears 2008). Figure 2.4 illustrates activity resources in Microsoft Project, whereby the EPOXY WALL CRACKS activity utilizes a laborer, grinder saw, and epoxy material in order to complete the activity. As detailed below, each resource has a corresponding

cost. The sum of all resources across all activities equates to the total value of the project.
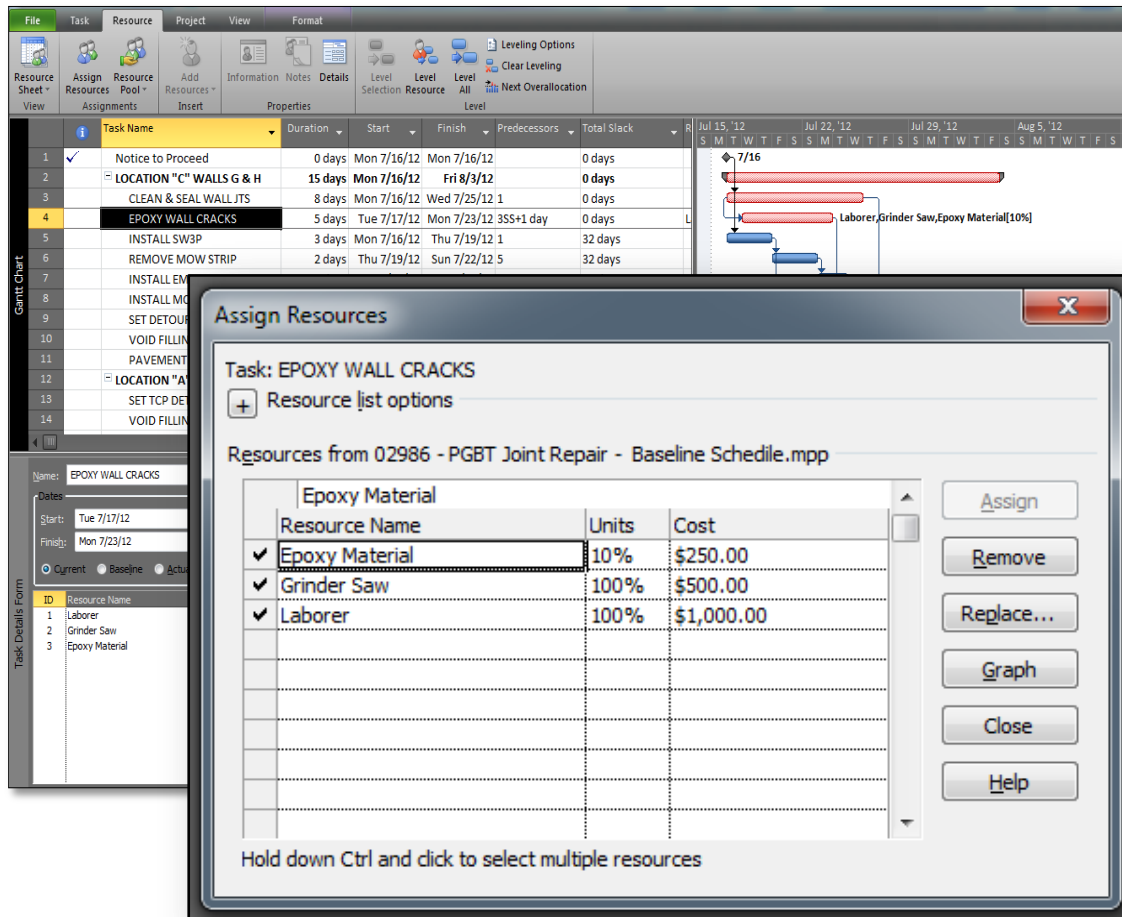
Figure 2.4: Resource Loading in Microsoft Project

5.   *Calculate the schedule and generate s-curve.*

The forward and backward pass are conducted to determine early and late starts dates, early and late finish dates, float, and the critical path. Traditionally performed by hand, this process is automated by scheduling software. Once the schedule is calculated, cost is distributed across the duration of the project and an s-curve can be generated. This baseline s-curve is often referred to as the Budgeted Cost of Work Scheduled

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(BCWS) Curve (Figure 2.5), as it represents the budgeted cost of work that is scheduled but not yet performed. It is a cumulative cost curve against which project performance is measured. It is interpreted in the following manner:

- The project begins in December 2011.

- At the end of February 2012, the project is scheduled to have expended $40M (black arrow).

- At the end of November 2012, the project is scheduled to have expended $80M (red arrow).

- The project is scheduled to finish in June 2012 and cost over $120M (Budget at Complete)
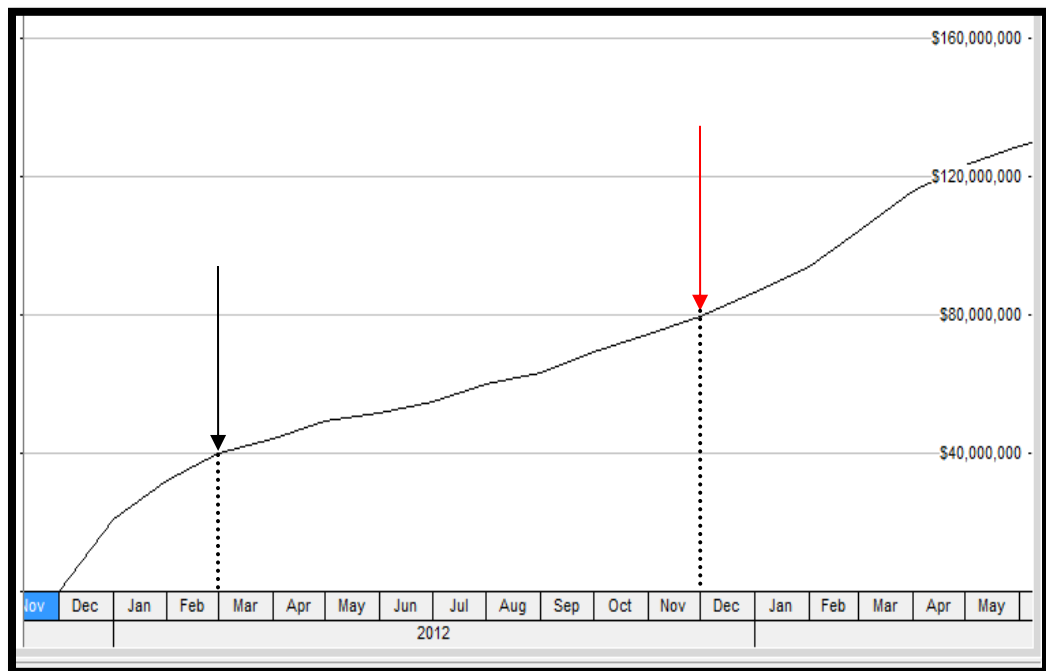
Figure 2.5: Example of BCWS Curve in Primavera

6.   *Update the schedule.*

Once the project is underway, actual costs and dates are entered into each active activity.   Reflect activities that are performed out of sequence by updating logic relationships.   Scheduled activities may also be updated if there are changes to the planned sequence of construction.

7.   *Analyze EV data.*

During construction, the BCWS curve is complimented by two additional curves, BCWP (Budgeted Cost of Work Performed) and ACWP (Actual Cost of Work Performed). These curves yield informative PPI.   From these curves project personnel can determine how much money it will cost (Estimate at Complete) and time it will take to complete the project (Planned Duration of Work Remaining).   Additionally, these curves "measure the amount of work [completed] in a unit of measure that is consistent and comparable with cost…by using the same unit of measure for physical progress as for cost" (Wilkens 1999).   In a glance, owners know how much of the project is complete and how much has been spent, so they can forecast costs leading to more accurate cash flows.   Contractors know whether they are within budget and on schedule, and they may determine whether additional resources are needed.   Figure 2.6 is an overview of the earned value curve during the course of a project.
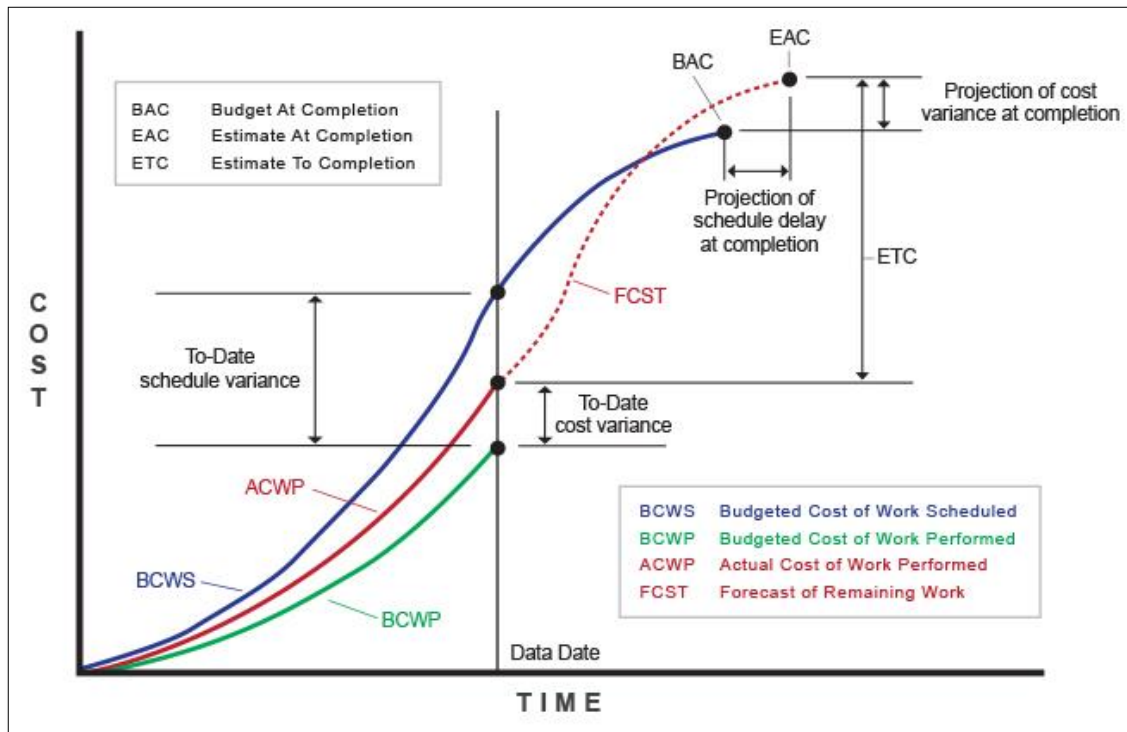
Figure 2.6: Labeled Earned Value Curve (Wilkens 1999)

2.2.3 PPI Derived from Traditional Earned Valued Management

In summary, the s-curve yields the following PPI:

- *Planned Duration of Work Remaining (PDWR) or Time Estimate to Complete, ETC(t)*
  PDWR is the anticipated amount of time remaining to complete the project. PDWR
  is the same as Time Estimate to Complete, ETC(t). The PDWR metric "has to be
  estimated, and heavily depends on the specific characteristics and the current status
  of the project" (Vandevoorde and Vanhoucke 2005). "Work Rate" is the estimated
  rate of completion based on how much work remains and the estimate rate of
  spending. It is represented by cost per time (e.g., dollars per day). Thus, ETC(t) is
  calculated using Equation 2.1.

$$\text{PDWR or ETC(t)} \ = \ \frac{\text{BAC} - \text{EV}}{\text{Work Rate}} \qquad \text{Eq. 2.1}$$

- *Time Estimate at Complete (EAC(t))*

  EAC(t) is the estimated total project duration based on actual project performance efficiency. It is a time forecasting tool used to predict the project's total duration. It is determined by adding the actual duration and the planned duration of work remaining (PDWR) represented by Equation 2.2:

$$\text{EAC(t)} = \text{AT} + \text{ETC(t)} \qquad \text{Eq. 2.2}$$

- *Planned Cost of Work Remaining (PCWR) or Forecast of Remaining Work (FCST) or Estimate to Complete (ETC)*

  The FCST or PCWR or ETC curve is the forecasted ACWP curve. This cost model predicts expenditure based on actual performance efficiency (Cost Performance Index and Schedule Performance Index). At any time AT, this interpolated curve is generated by forecasting cost from AT through project completion. This type of analysis improves the accuracy of cash flows and the anticipated project completion date. At any time AT, PCWR is calculated using the Equation 2.3:

$$\text{PCWR or ETC} \ = \ \frac{BAC - EV}{Performance\ Factor} = \frac{BAC - BCWP}{CPI\ or\ SPI} \qquad \text{Eq. 2.3}$$

- *Estimate at Completion (EAC)*

  EAC is the estimated total cost upon completion of the project based on actual project performance efficiency. EAC is perhaps the most highly requested PPI amongst project personnel. It is a cost forecasting tool determined by adding the actual cost to date and the planned cost of remaining work (PCWR). Most commonly, CPI is used as a discount factor to improve the accuracy of the remaining cost estimate, as CPI represents project-specific cost efficiency. SPI is used as a discount factor for projects in which the remaining duration greatly impacts final cost.

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This thesis will also discuss how to calculate EAC using more advanced metrics. Using traditional earned value metrics, EAC is represented by Equation 2.4:

$$\text{EAC} = \text{AC} + \text{ETC} = \text{AC} + \frac{BAC - EV}{CPI \text{ or } SPI} \qquad \text{Eq. 2.4}$$

- *Earned Value (EV)*

  EV represents "the amount budgeted for performing the work that was accomplished by a given point AT in time" (Vanhoucke 2009). This is also referred to as Budgeted Cost of Work Performed (BCWP) or periodic worth of the work that has been performed, and it is calculated using the following Equation 2.5:

$$\text{EV} = [\text{Total Activity (or Project) Budget at Complete}] *$$
$$[\text{Percent Activity (or Project) Complete}]$$
$$\text{or}$$
$$\text{EV} = \% \text{ Complete (at the particular point in time)} * \text{BAC} \qquad \text{Eq. 2.5}$$

- *Schedule Variance (SV)*

  SV is the difference between the budgeted cost of work performed and the budgeted cost of work scheduled, or the difference between earned value and planned value. It is expressed in a monetary unit as opposed to time unit. In essence, "SV measures a volume of work done (i.e., earned) versus a volume of work planned" (Vandervoorde and Vanhoucke 2005). It is a measurement of actual work accomplishment in relation to the planned or estimated accomplishment. If earned value exceeds planned value, then more work as been performed than what was planned at some time AT, and vice versa. SV is calculated using Equation 2.6:

$$\text{SV} = \text{BCWP} - \text{BCWS}$$
$$\text{or}$$

$$SV = EV - PV \qquad \text{Eq. 2.6}$$

SV is time-based indicator measured in terms of cost, thresholds vary from project to project based on risk strategy and schedule criticality. As noted by the developers of Microsoft Project 2007, the following threshold percentages may be used as guideline (Biafore 2012):

- Less than 5% = low risk tolerance

  SV less than 5% may serve as an early warning for potential problems.

- Between 5% and 10% = moderate risk

  SV in this range requires corrective action as detailed below.

- Greater than 10% = high risk

  SV in this range requires project personnel to take immediate and substantial action.

SV is analyzed in the following manner:

- SV values approaching zero indicate that the project is being executed at planned efficiency or production. In other words, actual dates are within a small margin of planned dates as per the baseline schedule.

- Positive SV can indicate a number of scenarios. If the schedule is accurate, positive SV is an indication that the project is ahead of schedule, as detailed in Figure 2.7. Higher SV values may indicate that the amount of time, cost, and/or resources required to complete the project was underestimated.

- Negative SV can indicate a number of scenarios. If the schedule is accurate, negative SV is an indication that the project is behind schedule. Exceedingly negative SV may indicate that the amount of time, cost, and/or resources required

to complete the project was overestimated. It may also indicate that the workforce

has incurred delays.
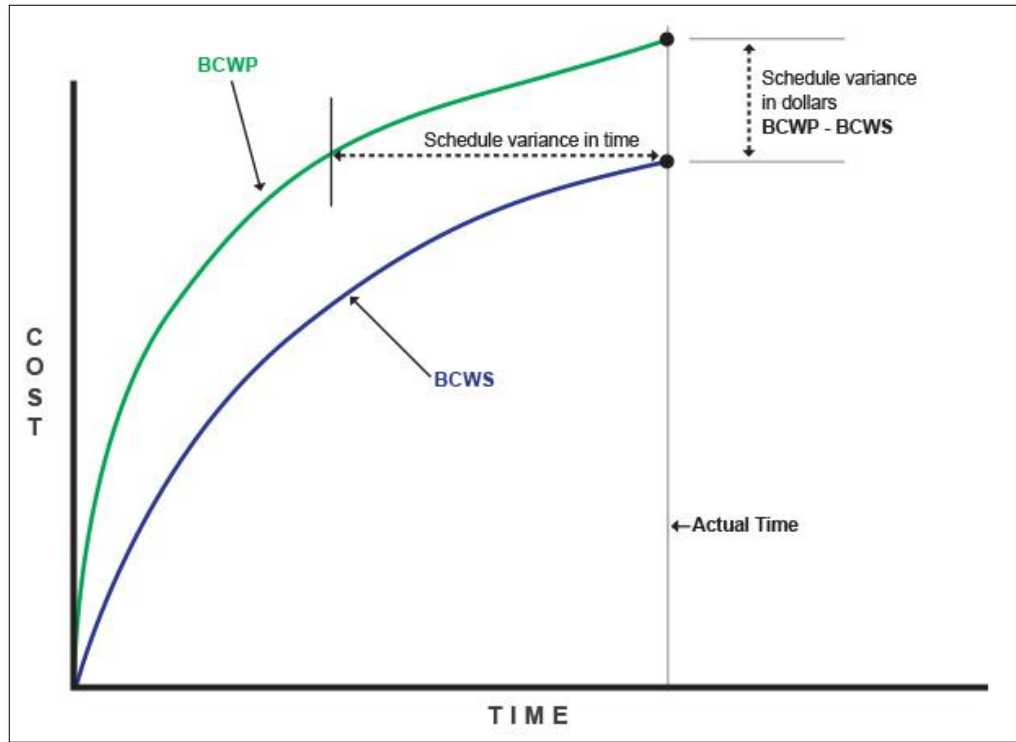
Figure 2.7: Example of a Project Ahead of Schedule using Schedule Variance (Hinze 2007)

- *Percent Schedule Variance (PSV or %SV)*

  PSV is a ratio indicating the project's percent deviation from the scheduled based on

  budgeted costs. This value represents an overview of actual schedule performance

  in relation to planned performance. PSV is calculated using either of the following

  formulae, Equation 2.7:

$$\text{PSV} = \frac{SV}{BCWS} * \mathbf{100}$$

or

$$PSV = \frac{BCWP - BCWS}{BCWS} * 100 \qquad \text{Eq. 2.7}$$

- *Schedule Performance Index (SPI)*

  SPI is a ratio that provides a direct relationship between actual work performed (BCWP) and work scheduled (BCWS). This PPI is a dimensionless indicator of the efficiency at which the project is utilizing time, PD (Planned Duration). SPI is calculated using Equation 2.8:

$$SPI = \frac{BCWP}{BCWS} = \frac{EV}{PV} \qquad \text{Eq. 2.8}$$

$$SPI > 1 \text{ indicates project is ahead of schedule}$$
$$SPI < 1 \text{ indicates project is behind schedule}$$

- *Cost Variance (CV)*

  CV is the difference between the budgeted cost of work performed and the actual cost of work performed, or the difference between earned value and actual cost. It is a measurement of the actual project cost in relation to planned or scheduled cost at a given time AT. If actual cost exceeds budgeted cost, then the project has incurred more cost than planned, and vice versa. The CV threshold is similar to the SV threshold as previously discussed. CV is calculated using either of the following formulae, Equation 2.9:

$$CV = BCWP - ACWP$$

$$\text{or}$$

$$CV = EV - AC \qquad \text{Eq. 2.9}$$

CV is analyzed in the following manner:

- CV values approaching zero indicate that the project is being executed at planned efficiency or production. In other words, actual costs are within a small margin of planned costs as per the baseline schedule.

- Positive CV values indicate the project is under budget. This is an indication that less money is spent to complete activities than what is budgeted for those activities. However, this may imply either better than planned production or excessive money is budgeted.

- Negative CV values indicate the project is over budget, as indicated in Figure 2.8. This is an indication that more money is spent to complete activities than what is budgeted for those activities. However, this may imply that either the activities are performed inefficiently or not enough money is budgeted to complete those activities. Again, negative CV values are warnings that the project may run over budget, so cost savings measures may be necessary to complete the project within budget.
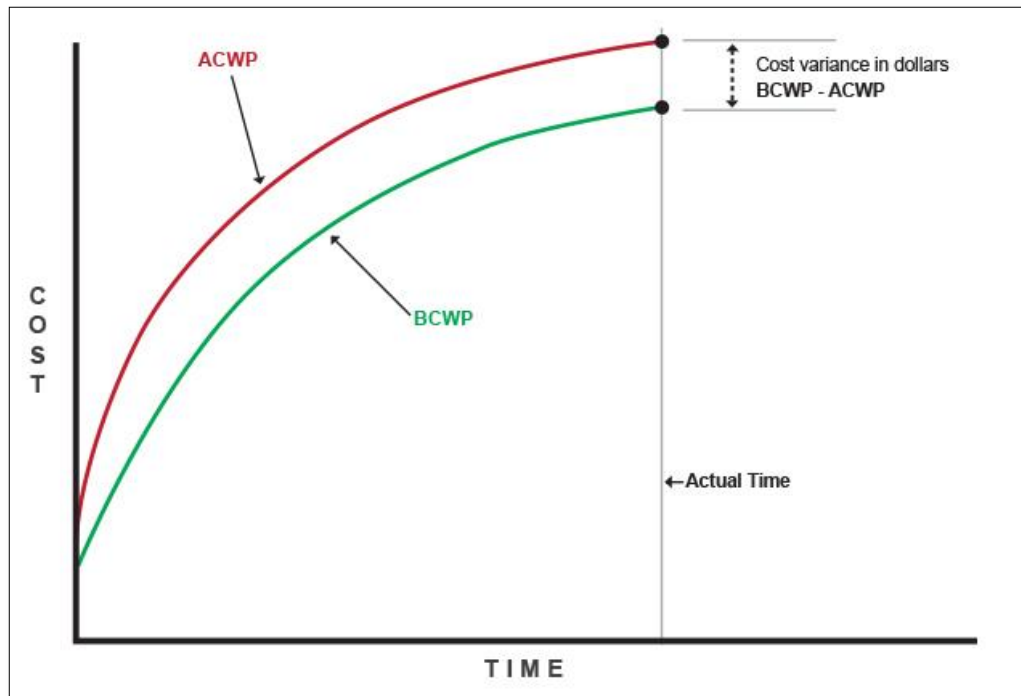
Figure 2.8: Example of a Project over Budget using Cost Variance (Hinze 2007)

- *Percent Cost Variance (PCV or %CV)*

  PCV measures the project's percent deviation of the actual cost from the budgeted cost of worked performed at time AT. This value represents an overview of actual cost performance in relation to planned expenditures. PCV is calculated using either of the following formulae, Equation 2.10:

$$PCV = \frac{CV}{BCWP} * 100$$

or

$$PSV = \frac{BCWP-ACWP}{BCWP} * 100 \qquad \text{Eq. 2.10}$$

- *Cost Performance Index (CPI)*

  CPI is a direct comparison of budgeted costs (BCWP) and actual costs (ACWP). CPI provides an overall indication of resource utilization efficiency, or cost efficiency. For example, a CPI value greater than 1.0 indicates that the work cost less than its budgeted amount. Therefore, the project is under budget, or it can be inferred that resources are being utilized efficiently. CPI is calculated using Equation 2.11:

$$\text{CPI} = \frac{BCWP}{ACWP} = \frac{EV}{AC} \qquad \text{Eq. 2.11}$$

$$\text{CPI} > 1 \text{ indicates project is under budget}$$
$$\text{CPI} < 1 \text{ indicates project is over budget}$$

Figure 2.9 is a simplified visual representation of the aforementioned PPI derived from Earned Value analysis. It is important to note that the cost and schedule variances yield a "snapshot" of the current status of the project, whereas the cost and schedule performance indices are representative of the evolution in performance of the project.
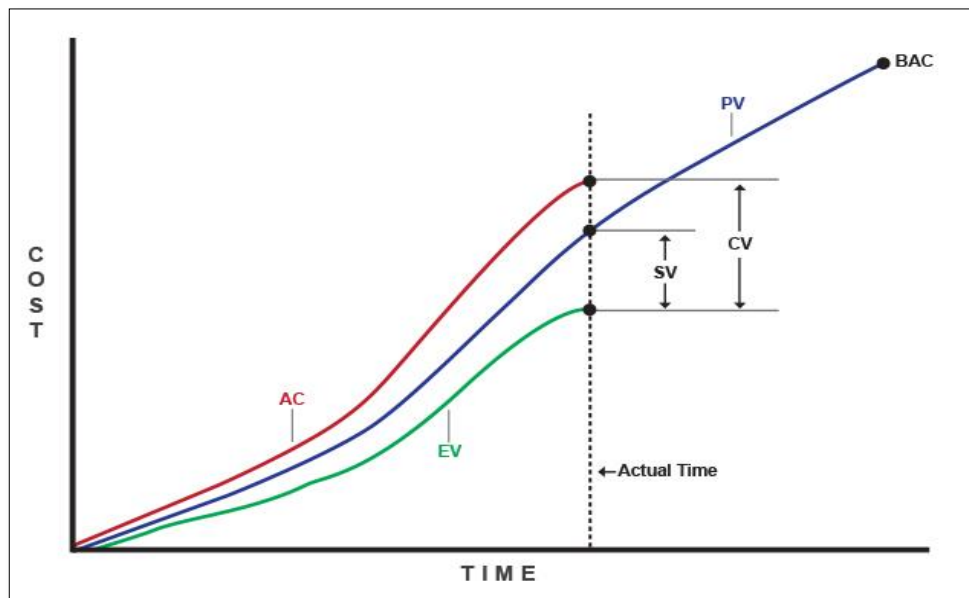
Figure 2.9: Overview of Earned Value PPI

- *Critical Ratio (CR) or Cost-Schedule Index (CSI) or Schedule-Cost Index (SCI)*

  The Critical Ratio (CR) is synonymous with the Cost-Schedule Index (CSI) and Schedule-Cost Index (SCI). CR is an overall indication of project health that combines both cost (CPI) and schedule (SPI) indicators. CR is calculated using Equation 2.12:

$$CR = SPI * CPI \qquad \text{Eq. 2.12}$$

$$CR > 1 \text{ indicates execution better than planned efficiency}$$
$$CR < 1 \text{ indicates execution worse than planned efficiency}$$

2.2.4. Known Issues with Traditional Earned Value

The following issues compromise the accuracy of PPI derived from traditional earned value analysis:

- The most significant issue with Traditional Earned Value is its crude method of calculating Time Estimate to Complete, ETC(t). Project personnel must estimate "Work Rate" based on the current status of the project. However, the status often fluctuates, which compromises the accuracy of this PPI.

- Schedule Variance (SV) is measured in terms of cost. Time is often more intuitive with regards to schedule analysis (Lipke 2003).

- An SV value equal to 0 (or SPI = 1) could indicate an activity is complete or the activity is being performed at planned efficiency.

- Towards the end of a project, as SV always converges to 0 and SPI always converges to 1. This indicates the achievement of planned performance/schedule efficiency, whereas the project may actually be behind schedule.

- There is a point in time when SV and SPI indicators become unreliable as tools to predict schedule performance. This period typically occurs over the last third of the

project, which can be considered the most critical time to obtain accurate PPI (Vandevoorde and Vanhoucke 2006).

<div align="center">2.3 Planned Value Method</div>

The Planned Value Method (PV) was developed by Frank Anbari in 2003. This method increases the accuracy and interpretability of schedule performance monitoring by translating SV and SPI from monetary units to time units (Vanhoucke 2009). In this way, schedule performance is analyzed with respect to time, which is more intuitive. The accuracy of PV data relies upon the accuracy of the Planned Duration (PD) value, which is the estimated duration of the entire project. PV analysis produces another value for the Estimate at Completion, EAC(t), which is estimated total duration of the project.

2.3.1. Key Elements of Planned Value Method

- *Planned Value Rate or Planned Accomplishment Rate (PV_{rate})*
  Planned Value Rate (PV_{rate}) is the average planned value per time period (e.g., dollars per day), or planned rate of accomplishment (Anbari 2003). It is defined as the baseline budget at complete (BAC) divided by the planned duration (PD) as detailed by Equation 2.13:

$$PVrate \ = \ \frac{BAC}{PD} \qquad\qquad \text{Eq. 2.13}$$

- *Time Variance (TV)*
  Time Variance (TV) is calculated in order to convert monetary units to time units (i.e., dollars to days. It is calculated using Equation 2.14:

$$TV \ = \ \frac{SV}{PVrate} \ = \ \frac{SV*PD}{BAC} \ = \ \frac{(EV-PV)*PD}{BAC} \qquad\qquad \text{Eq. 2.14}$$

2.3.2. PPI Derived from Planned Value Method

Using the Planned Value Method, there are three dependent values for the Estimate at Completion, EAC(t). Project personnel must select the ideal EAC(t) formula based on the current status of the project. The following three scenarios must be considered in order to improve the accuracy of the EAC(t) value.

1. *Duration of remaining work as planned [EAC(t)$_{PV1}$]*

   Scenario 1 is utilized to calculate EAC(t) when the duration of remaining work is trending as planned. In other words, the project is generally adhering to the baseline schedule in terms of duration.

$$\text{EAC(t)}_{PV1} = PD - TV$$
<div align="right">Eq. 2.15</div>

2. *Duration of remaining follows the SPI trend [EAC(t)$_{PV2}$]*

   Scenario 2 is utilized when the duration of remaining work follows the current SPI trend. This is evident in projects that obtain SPI values approaching one.

$$\text{EAC(t)}_{PV2} = \frac{PD}{SPI} \, TV$$
<div align="right">Eq. 2.16</div>

3. *Duration of remaining follows the SCI trend [EAC(t)$_{PV3}$]*

   Scenario 3 is utilized when the duration of remaining work follows the current SCI trend. This is evident in projects that obtain SCI values approaching one.

$$\text{EAC(t)}_{PV3} = \frac{PD}{SCI}$$
<div align="right">Eq. 2.17</div>

2.3.3. Known Issues with Planned Value

The Planned Value Method is known to produce inaccurate results towards the end of a project. As the project nears completion, the use of metrics generated from this method should be scrutinized prior to being reported to stakeholders.

<u>2.4 Earned Duration Method</u>

The earned duration method was developed by D. Jacob in 2003 and improved upon by Jacob and Kane in 2004. Earned duration (ED) forecasting is proven to be a reliable when EVM based PPI provides erratic results, such as "when a delay in a non-critical activity reports an overall project delay, although the project is still on track" (Vanhoucke 2008). The Earned Duration Method revolutionized the calculation EAC(t), as it assesses past performance in order to predict future performance. In essence, ED utilizes the current EV trend to forecast EAC(t), as detailed in Figure 2.10.
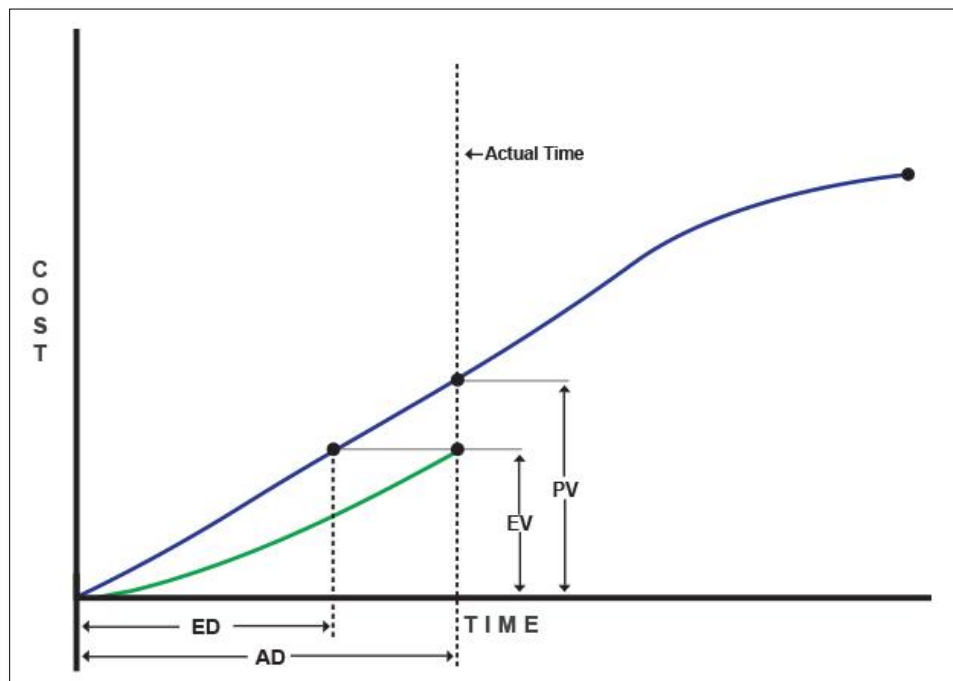
Figure 2.10: Representation of Earned Duration

2.4.1. Key Elements of Earned Duration Method

Earned Duration predicts future performance based on past performance. It is the product of actual duration (AD) and the schedule performance index (SPI), as detailed by Equation 2.18.

$$\text{ED} = AD * SPI$$

<div align="right">Eq. 2.18</div>

The earned duration forecasting method utilizes a performance factor (PF) to "adapt the future performance to the past performance (depending on the project characteristics)" (Vandevoorde and Vanhoucke 2006). The generic equation (Eq. 2.19) to solve for EAC(t) using the earned duration method is as follows:

$$\text{EAC(t)}_{ED} = AD + \frac{PD - ED}{PF}$$

<div align="right">Eq. 2.19</div>

2.4.2. PPI Derived from Earned Duration Method

Time Estimate at Complete

There are six possible values for EAC(t) when utilizing the Planned Duration Method, each dependent on the project status (i.e., the way in which the project is trending). The first set of formulas is utilized if the actual project duration is less than or equal to the planned project duration (i.e., AD ≤ PD).

1. *Duration of remaining work as planned [EAC(t)$_{ED1}$]: PF = 1*

   Scenario 1 is utilized to calculate EAC(t) when the duration of remaining work is trending as planned. In other words, the project is generally adhering to the baseline schedule in terms of duration.

$$\text{EAC(t)}_{ED1} = AD + \frac{PD - ED}{PF} = PD + AD * (1 - SPI)$$

<div align="right">Eq. 2.20</div>

2. *Duration of remaining follows the SPI trend [EAC(t)$_{ED2}$]: PF = SPI*

   Scenario 2 is utilized when the duration of remaining work follows the current SPI trend. This is evident in projects that obtain SPI values approaching one.

$$EAC(t)_{ED2} \; = \; AD + \frac{PD-ED}{SPI} \; = \; \frac{PD}{SPI} \qquad \text{Eq. 2.21}$$

3. *Duration of remaining follows the SCI trend [EAC(t)$_{ED3}$]: PF = SCI*

   Scenario 3 is utilized when the duration of remaining work follows the current SCI trend. This is evident in projects that obtain SCI values approaching one.

$$EAC(t)_{ED3} \; = \; AD + \frac{PD-ED}{SCI} \; = \; \frac{PD}{SCI} + \; AD * (1 - \frac{1}{CPI}) \qquad \text{Eq. 2.22}$$

The second set of formulas is utilized if the actual project duration is greater than or equal to the planned project duration (i.e., AD > PD). Under these scenarios, PD is substituted by AD in the above referenced formulas.

4. *Duration of remaining work as planned [EAC(t)$_{ED4}$]: PF = 1*

   Scenario 4 is utilized to calculate EAC(t) when the duration of remaining work is trending as planned. In other words, the project is generally adhering to the baseline schedule in terms of duration.

$$EAC(t)_{ED4} \; = \; AD + \frac{AD-ED}{1} = AD * (2 - SPI) \qquad \text{Eq. 2.23}$$

5. *Duration of remaining follows the SPI trend [EAC(t)$_{ED5}$]: PF = SPI*

   Scenario 5 is utilized when the duration of remaining work follows the current SPI trend. This is evident in projects that obtain SPI values approaching one.

$$EAC(t)_{ED5} \; = \; AD + \frac{AD-ED}{SPI} \; = \; \frac{AD}{SPI} \qquad \text{Eq. 2.24}$$

6. *Duration of remaining follows the SCI trend [EAC(t)$_{ED6}$]: PF = SCI*

Scenario 6 is utilized when the duration of remaining work follows the current SCI trend. This is evident in projects that obtain SCI values approaching one.

$$\text{EAC(t)}_{\text{ED6}} \ = \ AD + \frac{AD-ED}{SCI} \ = \ AD * (1 - \frac{1}{CPI} - \frac{1}{SCI}) \qquad \text{Eq. 2.25}$$

To Complete Schedule Performance Index

Jacob also developed "an assessment metric [which] measures the additional effort needed to finish the project with the project deadline" (Vandevoorde and Vanhoucke 2006). This PPI, known as To Complete Schedule Performance Index (TCSPI), is considered a corrective action metric, and it is a quantitative representation of measures that need to be taken in order to finish the project within the planned duration (PD). In reality, this could represent the need to accelerate the schedule by, for instance, adding additional resources or working more shifts. TCSPI is calculated using the Equation 2.26:

$$\text{TCSPI} \ = \ \frac{PD-ED}{PD-AD} \qquad \text{Eq. 2.26}$$

Alternatively, TCSPI can be calculated using the latest revised schedule (LRS) duration, "which is an updated planned duration after an intermediate corrective action taken during the project life time" (Vandevoorde and Vanhoucke 2006). TCSPI$_{\text{LRS}}$ is calculated using Equation 2.27:

$$\text{TCSPI}_{\text{LRS}} = \ \frac{PD-ED}{LRS-AD} \ \ \text{where} \qquad \text{Eq. 2.27}$$

$$\text{LRS} = \text{PD as per the most current schedule update}$$

2.4.3. Known Issues with Earned Duration

The Earned Duration Method is known to produce unreliable results towards the end of a project. As the project nears completion, the use of metrics generated from this method should be scrutinized before reported to stakeholders.

2.5 Earned Schedule Method

The Earned Schedule Method was developed by Lipke in 2002 and improved upon by Henderson in 2004. Like the Planned Value and Earned Duration methods, Earned Schedule (ES) reports schedule performance measures in units of time, as opposed to cost. Earned Schedule "is determined by comparing the cumulative Budgeted Cost of Work Performed (BCWP) earned to the performance baseline, Budgeted Cost of Work Scheduled (BCWS). The time associated with BCWP (i.e., ES) is founded from the BCWS S-curve" (Lipke 2003). In essence, "Earned Schedule is the point in time when the current Earned Value was to be accomplished" (Stratton 2006).

The Earned Schedule Method is perhaps the most accurate duration forecasting method, as it maintains accuracy through the completion of the project. Represented by Equation 2.28, "cumulative ES is the number of completed PV time increments EV exceeds PV plus the fraction of the incomplete PV increment in the unit of time (i.e., weekly or monthly being utilized)" (Henderson 2007).

$$\text{ES} \; = \; N + \frac{EV - PVn}{PVn{+}1 - PVn} \qquad \text{where} \qquad \text{Eq. 2.28}$$

N is the time increment of the PV that is less than the current PV
EV is the Earned Value at Actual Time, AT
PV_n is the Planned Value at time n
PV_{n+1} is the Planned Value at time n+1

As detailed by Figure 2.11, "the earned value at a certain (review) point in time is traced forwards or backwards to the performance baseline (S-curve) or PV. This intersection point is moved downwards on the X-axis (the time scale) to calculate the earned schedule ES" (Vandevoorde and Vanhoucke 2006). Using Figure 2.11 as an example, ES is calculated using Equation 2.29:

$$\text{ES} \ = (Jan\ thru\ May) + (Portion\ of\ June)$$

$$= \ 5 + \ \frac{\text{EV}-\text{PV}(May)}{\text{PV}(June)- \text{PV}(May)} \qquad \text{Eq. 2.29}$$
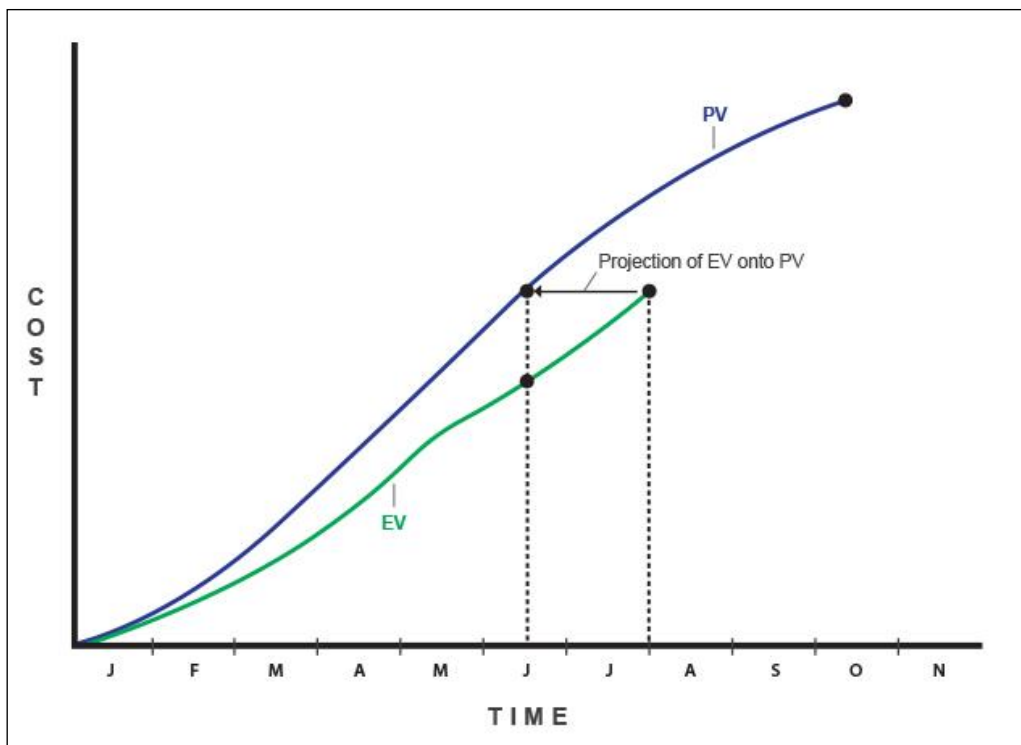
Figure 2.11: Example of Earned Schedule Calculation

2.5.1. Key Elements of Earned Schedule Method

- *Schedule Variance with Earned Schedule (SV(t))*

  $SV(t)_{ES}$ is a time-based PPI unlike SV derived from traditional earned value, which is cost-based. $SV(t)_{ES}$ is more intuitive, as time is more easily assimilated with schedule. Additionally, "the behavior of $SV(t)_{ES}$ over time results in a final $SV(t)_{ES}$ that equals exactly the real time difference at completion (while SV always ends at zero)" (Vandevoorde and Vanhoucke 2006). $SV(t)_{ES}$ is calculated using Equation 2.30:

$$SV(t)_{ES} = \ ES - AT$$ Eq. 2.30

  $SV(t)_{ES} > 1$ indicates the number of times units
  the project is ahead of expected performance

  $SV(t)_{ES} < 1$ indicates the number of times units
  the project lags behind expected performance

- *Schedule Performance Index with Earned Schedule (SPI(t))*

  $SPI(t)_{ES}$ is also a time-based PPI unlike SPI derived from traditional earned value, which is cost-based. This improved both the accuracy and ability to interpret this PPI. At the end of the project, the final value of $SPI(t)_{ES}$ reflects the actual project schedule performance, whereas SPI always equals 1. $SPI(t)_{ES}$ is calculated using Equation 2.31:

$$SPI(t)_{ES} \ = \ \frac{ES}{AT}$$ Eq. 2.31

  $SPI(t)_{ES} > 1$: ES exceeds AT, which indicates better than planned
                          performance efficiency

  $SPI(t)_{ES} < 1$: AT exceeds ES, which indicates worse than planned
                          performance efficiency

2.5.2. PPI Derived from Earned Schedule Method

Time Estimate at Complete

There are three possible values for EAC(t) when utilizing the Earned Schedule Method, each dependent on the project status (i.e., the way in which the project is trending). The generic formula to calculate EAC(t) using the earned schedule method is as follows (Eq. 2.32):

$$\text{EAC(t)}_{ES} \ = \ AD + \frac{PD-ES}{PF} \hspace{2cm} \text{Eq. 2.32}$$

1. *Duration of remaining work as planned [EAC(t)$_{ES1}$]: PF = 1*

   Scenario 1 is utilized to calculate EAC(t) when the duration of remaining work is trending as planned. In other words, the project is generally adhering to the baseline schedule in terms of duration.

$$\text{EAC(t)}_{ES1} \ = \ AD + \frac{PD-ES}{1} \hspace{2cm} \text{Eq. 2.33}$$

2. *Duration of remaining follows the SPI trend [EAC(t)$_{ES2}$]: PF = SPI*

   Scenario 2 is utilized when the duration of remaining work follows the current SPI trend. This is evident in projects that obtain SPI values approaching one.

$$\text{EAC(t)}_{ES2} \ = \ AD + \frac{PD-ES}{SPI} \ = \ \frac{PD}{SPI} \hspace{1.5cm} \text{Eq. 2.34}$$

3. *Duration of remaining follows the SCI trend [EAC(t)$_{ES3}$]: PF = SCI*

   Scenario 3 is utilized when the duration of remaining work follows the current SCI trend. This is evident in projects that obtain SCI values approaching one.

$$\text{EAC(t)}_{ES3} \ = \ AD + \frac{PD-ES}{SCI} \ = \ \frac{PD}{SCI} + AD * (1 - \frac{1}{CPI}) \hspace{1cm} \text{Eq. 2.35}$$

2.5.3. Known Issues with Earned Schedule

Though the Earned Schedule Method provides a more intuitive method of monitoring schedule performance by reporting schedule PPI in terms of time, like the Earned Value Method, this analysis focuses on execution efficiency. As such, these methods are unable to indicate whether the project adhered to the original plan in terms of construction sequence. "If compliance to the plan is not upheld then the likelihood of delays, disputes regarding payment milestones, [and] potential litigation surrounding the cause and effect of change" become more prevalent (Patterson 2011). Thus, in order to gain a complete perspective of the project status, it is necessary to gather PPI pertaining to additional schedule input and output.

2.6 EVMS in Contract Specifications

In order to ensure that construction schedules contain the necessary data to conduct Earned Value analysis, it is important for contracts to explicitly state the required schedule input. The following list identifies language that will prompt schedulers to include the necessary schedule input.

- Some contracts require schedulers to provide earned value data such as performance curves (S-curves), planned values, earned values, and actual values in a separate document in addition to the schedule. This is ideal in the case that reviewers of the schedule do not possess resources to perform earned value analysis.

- The schedule requires a sufficient level of detail as to allow day-to-day monitoring of operations. This is especially important in the event that physical measurement or monitoring is required to confirm the status of activities.

- In the baseline schedule, the contractor shall cost load the schedule. This implies that all activities will be assigned the planned or budgeted cost to complete the activity. The sum of all budgeted activity costs equals the total contract value.

- All activities shall be linked with logical relationships. The only open-ended activities shall be the first activity and the last activity. This ensures that changes to construction sequence do not affect the time when which cost is incurred.

- All activities shall be updated with actual cost upon completion of the activity.

- Once the activity has started, the activity is assigned a status of progress, preferably physical percent complete and remaining duration. Actual start and finish dates shall also be assigned. Additionally, all out of sequence activities shall be corrected with each schedule update.

2.7 Chapter 2 Summary

Chapter 2 provided an overview of Earned Value Management including the advanced earned value methodologies and how to implement an Earned Value Management System. This chapter also expands on the PPI obtained from earned value analysis and the equations to derive these PPI. Additionally, schedule specification language is provided to include in contracts when promoting the use of Earned Value Management. Comparison charts of EVMS variables presented by traditional earned value, planned value, earned duration, and earned schedule are located in Appendix B.

CHAPTER 3

PROJECT PERFORMANCE INDICATORS: RESOURCES

Materials, labor, and equipment resources are crucial elements of both the project and its schedule, as "success on construction projects depends on the efficient utilization of limited and costly resources" (Sears 2008). In order to gather resource-related PPI, contactors must "resource-load" the baseline schedule, as well as update completed activities with actual resource utilization in each monthly progress schedule. In doing so, schedule reviewers are able to monitor the actual resource utilization versus the planned resource utilization.

3.1 Resource-Loading the Schedule

Resource-loading the baseline schedule implies assigning planned labor (e.g., operators, laborers, crews, etc.), equipment (e.g., rollers, back hoes, cranes, etc.), and material (e.g., cubic yards of concrete, square yards of sod, etc.) required to complete each activity, as detailed above in Figure 2.4 of Chapter 2. The maximum number of resources available to perform the scope of work is a separate input variable also assigned to each activity. As activities are completed, schedulers update activities with the actual resources utilized to complete the activity, which may differ from the planned resource value.

A resource-loaded baseline schedule is representative of all the material, labor, and equipment required to construct the project. Additionally, "a resource-loaded schedule..clearly indicates to all parties the fundamental interdependencies between activities and resources under which the contractor will be performing work" (Sears 2008). As is the nature of most construction projects, changing the plan is common whether it be an alternate construction sequence or additional scope of work. It is important to capture the affects of the change as it

relates to resources, which helps to develop a basis for the cost of change. Additionally, resource tracking may help answer the following question:

Is the contractor utilizing the resources it committed to using per the baseline schedule, and if not, is the contractor behind schedule?

There are implications of failing to meet resource commitments. Among other things, the contractor may be required to mobilize additional resources to bring the project back on schedule.

<u>3.2 PPI Derived from Resource-Loading</u>

3.2.1. Baseline Resource Utilization Graph

Baseline utilization graphs are generated to visualize a contractor's planned resource utilization. These graphs indicate both the type of resource and the point in time when the resource is planned to be utilized on the project. This graphical representation helps determine which and how many resources are required to complete the project. With this knowledge, project personnel can verify that the contractor plans to utilize ample resources to construct the project. By verifying that the resources correspond to the scope of work, this process is also a check of whether the entire scope of work is accounted for in the schedule. Furthermore, owners can use these graphs as a planning tool by aligning inspection efforts with the contractors planned resource schedule. Figure 3.1 illustrates a baseline resource utilization graph from a Primavera Project Management schedule, and it is interpreted in the following manner:

- The resource (e.g., labor force) will begin work on the project in March 2011 utilizing just fewer than 60 units.
- The labor force is scheduled to reach nearly 120 units in May 2011 and almost 150 units in September 2011.
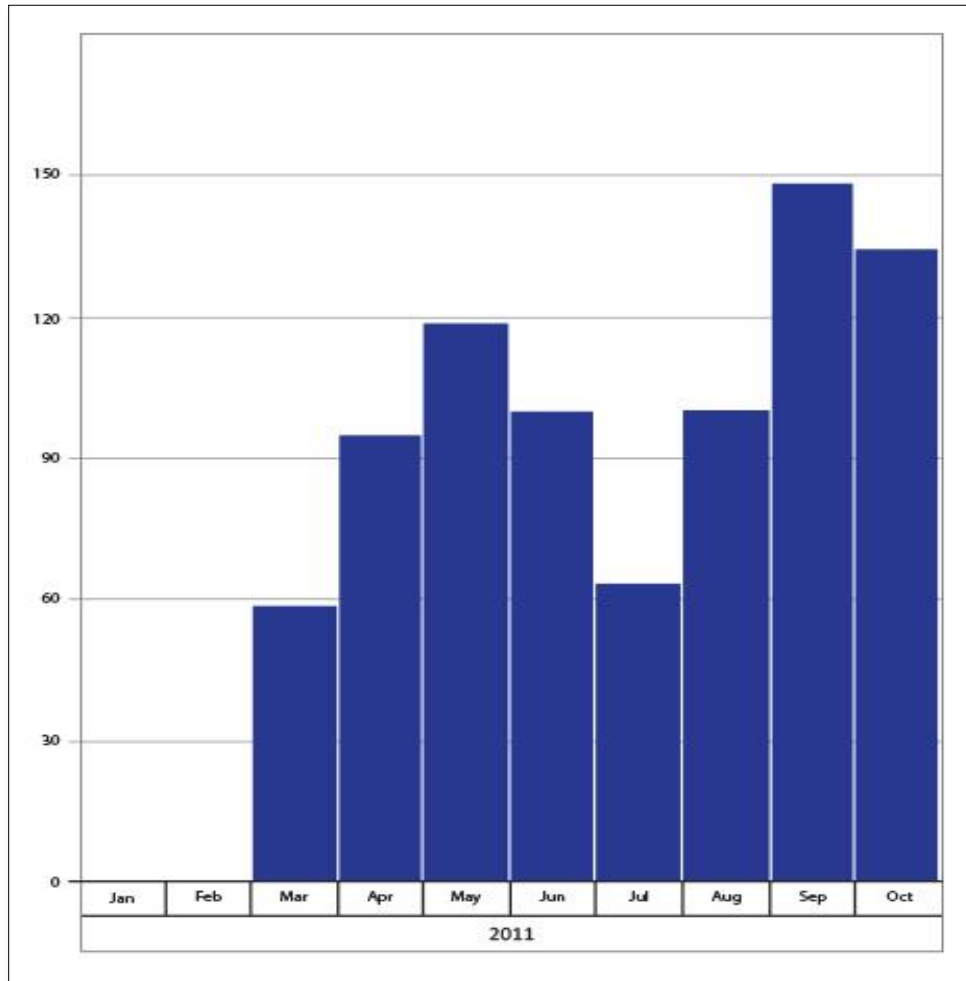
Figure 3.1: Baseline Resource Utilization Curve

3.2.2. Progress Resource Utilization Graphs

As activities are completed, progress resource utilization graphs are generated to analyze the variance between planned and actual resource utilization. This informative PPI illustrates whether the contractor is meeting planned resource commitments. If the contractor is not meeting its resources commitments and the project is behind schedule, then the contractor is delaying itself. This is a crucial implication in the defense of construction claims. Figure 3.2 is an example of a progress resource utilization graph, and it is interpreted in the following manner:

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- The contractor exceeded its planned resource (e.g., dump trucks) in the month of July 2010 by a small margin.
- In September 2011, the contractor utilized X less dump trucks than it planned to use during this time period.

This is only the first step of the analysis, as it is necessary to determine whether the resources affected the performance of the project. For instance, one must determine if the late schedule is a direct result of insufficient resources.
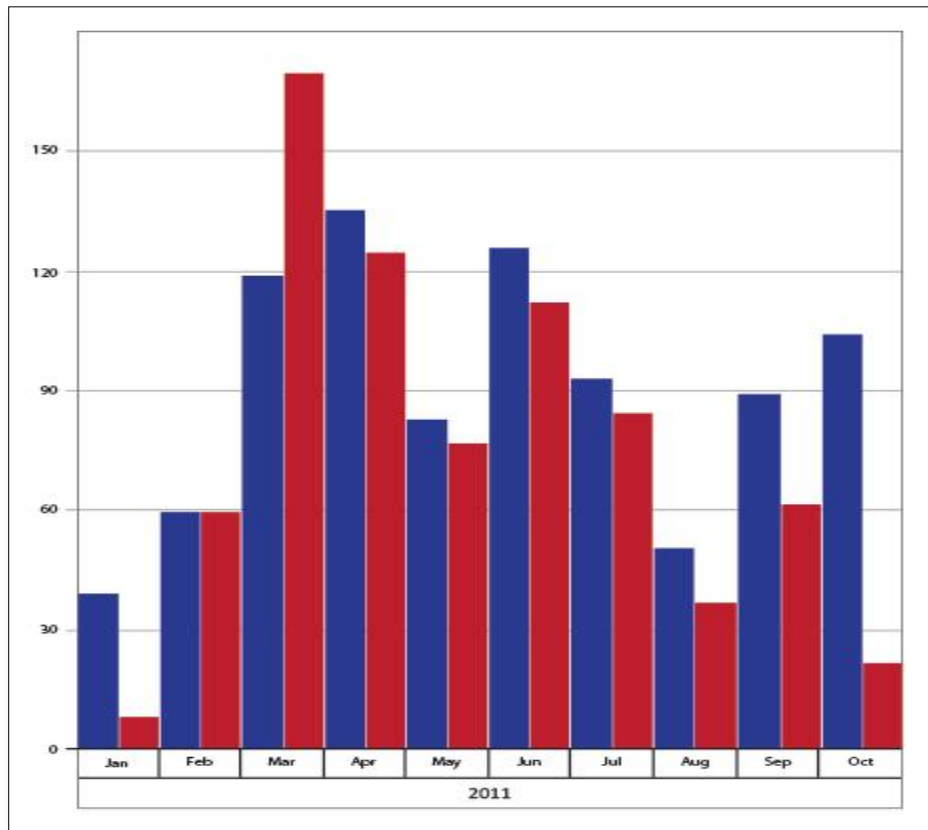
Figure 3.2: Progress Resource Utilization Graph

3.2.3. Critical Resources

Critical Resources are those resources that drive critical activities. The availability and performance of Critical Resources are vital to the completion of critical activities. Since critical

activities drive the completion date, Critical Resources ultimately affect the timely completion of a project. As such, it is important to identify and report Critical Resource so that project personnel can monitor their performance and corresponding scope of work.

3.3 Resource Utilization in Contract Specifications

In order to ensure that construction schedules contain the necessary data to generate resource utilization graphs, it is important for contracts to explicitly state the required schedule input. The following list identifies language that prompts schedulers to include the necessary schedule input.

- All activities shall be resource-loaded. Provide detail indicating the labor, equipment, and materials required to complete the entire scope of work associated with each activity.
- The contractor must perform the work with sufficient resources to assure the completion of the project within the scheduled duration.
- If the schedule is late as a result of insufficient resources or other reasons, the contractor shall provide a recovery schedule detailing how the contractor will set the project back on schedule. If additional resources are required, provide a narrative indicating both the type and amount of additional resources needed to complete the project on schedule.

3.4 Chapter 3 Summary

Chapter 3 provided an overview of construction resources including how to resource-load a schedule and produce resource utilization graphs. This chapter also described how to analyze resources as PPI by interpreting resource utilization graphs. Finally, this chapter provided scheduling specification language to include in contracts for the purpose of requiring resource-loaded schedules.

CHAPTER 4

PROJECT PERFORMANCE INDICATORS

TECHNICAL ATTRIBUTES

A construction schedule is a complex contract document, as each activity carries a series of technical attributes pertaining to the status of the project. This chapter examines PPI relating to the technical attributes of each activity such as float, criticality, and adherence to the original plan (baseline compliance). By examining these PPI, project personnel can develop "a better understanding as to where and when compliance is falling short, [which results] in a better chance of proactively focusing on those activities that require remediation and acceleration" (Patterson 2011).

4.1 PPI Derived from Technical Attributes

Much information can be inferred about project status based on the schedule's technical attributes. For example, "the measurements for revised durations and revised logic indicate how well the project team did in preparing the baseline schedule" (Nardella 2007). Though technical attributes are identified at the activity level, when analyzed collectively, these attributes help determine whether a project will finish on time.

4.1.1 Compliance to Baseline Schedule

Start Compliance

Start Compliance is the measure of an activity's adherence to its baseline start date. In other words, this PPI measures the variance between an activity's scheduled start date and its actual start date. Low start compliance indicates that preceding activities are being delayed, which signifies that the project is running behind schedule. Conversely,

high Start Compliance indicates compliance to the baseline schedule and a well-executed project. To calculate Start Compliance, follow the process indicated below:

1. In the baseline schedule, count the number of activities that are scheduled to start in a given time period.
2. In the update schedule, count the number of activities that started early, on-time, and late.
3. Start Compliance is the number of activities schedule to start divided by the number of activities that actually started on-time, and it is expressed as a percentage.
4. Tabulate this data, as detailed in the example illustrated by Table 4.1.

Finish Compliance

Finish Compliance is the measure of an activity's adherence to its baseline finish date, which is the variance between the baseline scheduled finish date and the actual finish date. As many individual activities finish late, so does the project. The opposite is also true; the project tends to finish on time when individual activities finish on time. To calculate Finish Compliance, follow the process indicated below:

1. In the baseline schedule, count the number of activities that are scheduled to finish in a given time period.
2. In the update schedule, count the number of activities that finished early, on-time, and late.
3. Finish Compliance is the number of activities schedule to finish divided by the number of activities that actually finished on-time. It is expressed as a percentage.
4. Tabulate this data, as detailed in the example illustrated by Table 4.1.

Table 4.1: Compliance Tabulation (Patterson 2009)

Group	Metric	Jan - 2011	Feb - 2011	Mar - 2011	Apr - 2011	May - 2011	TOTAL
Baseline	Scheduled/Baselined to Start	4	1	4	0	1	10
	Scheduled/Baselined to Finish	2	1	4	0	3	10
Updated Schedule	Start/ed	2	4	1	2	1	10
	Finish/ed	1	3	1	3	2	10
Statistics	Start/ed on Time	2	0	0	0	1	3
	Start/ed Early	0	0	2	0	0	2
	Start/ed Late	2	1	2	0	0	5
	Finish/ed on Time	1	1	1	0	2	5
	Finish/ed Early	0	0	1	0	1	2
	Finish/ed Late	1	0	2	0	0	3
	Start/ed on Time, Finish/ed Late	0	0	1	0	0	0
Compliance	Start Variance	2	1	4	0	0	7
	Cum Start Variance	2	3	7	7	7	-
	Start Compliance	50%	0%	0%	N/A	100%	30%
	Finish Variance	1	0	3	0	1	5
	Cum Finish Variance	1	1	4	4	5	-
	Finish Compliance	50%	100%	25%	N/A	67%	50%

Based on the example illustrated by Table 4.1, the following conclusions can be drawn:

- Start Compliance started at 50% in January 2011 and continued to slip, which indicates relatively poor Start Compliance.

- Finish Compliance started at 50% in January 2011, improved to 100% in February 2011, and slipped through the end of the project.

- The total Start Compliance was 30% and the total Finish Compliance was 50%, which indicates that 30% of all activities started on-time and 50% of all activities finished on-time.

- There were no planned start or finish dates in April 2011, whereas there were 2 actual starts and 3 actual finishes. This indicates a project with relatively poor schedule compliance.

Duration Compliance

Duration Compliance is the measurement of how closely activities adhere to their planned duration, or original duration. In essence, many activities taking longer than planned to complete may indicate that the project is behind schedule. The opposite is true; if activities are finishing sooner than planned, then the project is either ahead of schedule or the original durations are higher than necessary. To determine Duration Compliance, follow the guidelines below.

- Examine the actual duration of completed activities and compare it to the original duration.

- Identify those activities that exceed planned duration, finish sooner than planned, and finish per the original duration.

Activity Suspension

A suspension occurs when an activity has started but was not actively worked on during the update period. Suspensions are identified by analyzing activities that have an actual start date but maintain the same percent complete (or progress) between two update periods. A suspended activity may indicate a lack of resources to perform the work, a change in construction sequence, or "by actions or inactions of parties not under the contractor's control" (Winter 2008).

When a project fails to meet its planned start and finish dates, the accuracy of the entire schedule is called into question. Ideally, the baseline schedule is accepted by all parties prior to construction and is considered a commitment on the part of contractors. If the contractor is unable meet baseline goals, then it may indicate that the contractor is planning the

work during the course of construction. Ultimately, "the late planning yields schedule delays and cost impacts that could have been avoided or dealt with much earlier in the project" (Nardella 2007).

4.1.2 Logic

The logic in a schedule refers to the "relationship" between activities (e.g., start to start, finish to start, etc.), which establishes the sequence of construction. Logic is a key driver of an activity's completion date. Inaccurate logic may lead to inaccurate completion dates and "overly optimistic cost forecasting," which can alter the critical path and promote poor financial decisions (Patterson 2010). Logic is a crucial PPI, as it "ensures that the schedule is both correctly linked as well as not over linked with regards to complexity" (Patterson 2010). In terms of PPI, it is important to record the number of activities with revised logic in each update schedule. There two main forms of inaccurate logic: missing logic and overuse of logic.

Missing Logic

Missing logic implies that an activity is devoid of a logical relationship with another activity. In essence, if an activity is directly affected by another activity, then the two activities should be tied logically.

Overuse of Logic

Overuse of logic, or over linked activities, implies that an activity is linked to more activities than is necessary. When an activity is linked to many other activities, there is a higher risk of those activities impacting the schedule similar to a "snowball" effect.

In addition to verifying the construction sequence and proper use of logic, it is important to identify whether the logic links contain lags or leads. Lags and leads are used to accelerate or delay the sequence of activities. This implies that the logic of a successor activity cannot initiate until the lag or lead period transpires, which often impacts the critical path. Furthermore,

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since lags and leads are simply additional duration assigned to an activity, they are void of detail. This adds to the complexity of managing and controlling the schedule.

Analyzing logic is yet another means of measuring how well the project team is following the accepted baseline schedule. When activities are performed out of sequence, this may result "in the team's decision to compress the subsequent work activities in order to hold the required project completion date" (Nardella 2007). Inevitably, changes to construction sequence leads to cost impacts on the part of owners and contractors. Contractors may lose operational efficiency, while owners may have pulled investments out early to pay for work that was planned but not executed.

4.1.3 Constraints

Constraints are restrictions placed on an activity resulting in an artificial date on which the activity must start or finish. In other words, "constraints are forced-date overrides to computed CPM dates, [which] hide the pure logical relationships between activities" (Winter 2008). Typically, only contractual milestone activities with assigned dates should be constrained. All other constraints should be avoided, as "adding non-contractual constraints reduces activity float that may later become critical" (Winter 2008). There are two categories of constraints:

One-Way Constraint

One-way constraints confine the start or completion of an activity to a set of dates. For example, a "start no earlier than" constraint requires the activity to start anytime after a certain date. Similarly, a "finish no later than" constraint requires the activity to finish some time before a certain date. If the activity is unable to satisfy the constraint, then the activity retains negative float. The negative float value indicates how much time the activity is behind schedule.

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Two-Way Constraint

Two-way constraints restrict the activity to a single date. For example, a "must start on" constraint requires that the activity start on a specific date. Additionally, a "must finish on" constraint requires that the activity finish on a specific date. Float is evaluated in the same manner as one-way constraints. Two-way constraints should be avoided, "as they go against the very essence of CPM scheduling when calculated Start and Finish dates" (Patterson 2010).

Constraints are not considered PPI when analyzed independently. However, they are important to identify because they affect the accuracy of other PPI. As such, it is important to identify all constraints and ensure that only contractual milestones (e.g., Notice to Proceed, Substantial Completion, and Final Acceptance) are constrained. This ensures that the CPM method is properly utilized to calculate completion dates. However, "constraints may be added to the schedule if documented in a narrative and can be shown to not unfairly reserve available float for the exclusive use of one party" (Winter 2008).

4.1.4 Float

Float is described "as the period between the earliest possible start time for an activity not on the critical path and the latest time the activity can possibly finish, minus the actual number of days to do the work" (Korman 2011). It is an indication of the criticality of an activity. In general, lower float values (including negative numbers) result in higher criticality, and vise versa. A detailed analysis of float may "determine which sequence of activities [yields] the biggest benefit in terms of either accelerating or adding additional work to the sequence" (Patterson 2010).

Total Float

Total float represents the amount of time by which the activity can be delayed without delaying the project completion date. Total float is the different between an activity's

early start (ES) and late start (LS) dates or the difference between early finish (EF) and late finish (LF) dates.

$$\text{Total Float} \ = \ ES - LS \ = \ EF - LF \qquad \text{Eq. 4.1}$$

Free Float

Free float is the amount of time by which an activity can be delayed without delaying the early start of its successor activities. In other words, "free float is the amount of time an activity can be delayed without taking away float from later activities" (Newitt 2009). An activity's (Activity i) free float is calculated by subtracting its earliest finish time from the earliest start time of its successor activities (Activity j).

$$\text{Free Float} \ = ES_j - EF_i \qquad \text{Eq. 4.2}$$

Negative Float

Negative float is "obtained by having a fixed project start date and a fixed project finish date, where the finish date is set at a time earlier than would be calculated by the forward pass" (Newitt 2009). In general, the lowest negative float value equals the amount of days the project is behind schedule. As a form of PPI, negative float "should be seen as a great way of pinpointing impossible scenarios within a schedule" (Patterson 2010). Negative float should not be allowed in the baseline schedule without consent. However, "update schedules may indicate negative float, [as] this is a matter of status and logic and cannot be avoided if the project is running late" (Winter 2008).

Shared Float

Depending on the contract specification, float may be considered a project resource that is shared between the contractor and the owner. In this way, the project owns the float, thus the first party (owner or contractor) to need the extra time is able to use it.

The total project float is "the period between the scheduled completion date and the contract's completion date" (Korman 2011). In construction law, "judges have shown a tendency to support sharing for the good of the project, probably because it emphasizes the civic, public character of construction" (Korman 2011). Owners may consume float when changing the scope of work or reviewing submittals, while the contractor may use float if it encounters issues during construction. Conversely, some contract specifications may specify one party as the sole owner of the float. It is critical for every contract to establish which party owns the project float.

The execution of critical activities is perhaps most important to ensure the timely completion of the project, as a delay of a critical activity is a delay to the entire project. However, critical activities provide little opportunity for adjustment because they have no float. Activities with positive float allow for more precise management, as project personnel "can make decisions to start, interrupt, or complete the float activities as desired to fine-tune the project" (Newitt 2009).

Another valuable PPI related to float is the number of activities that are altered (duration, resources, constraints, etc.) in order to create float. Significant changes in float value are not possible without changing the nature of the activity. Furthermore, an activity may appear less critical than it is with the addition of float. It important to identify these altered activities, as they may indicate either the project is not adhering to the original plan or the plan needs to be revisited.

4.2 Technical Attributes in Contract Specifications

In order to ensure the obtainment of technical attribute PPI, it is important to outline the technical attribute requirements within contract scheduling specifications. In this way, contractors are aware of owner expectations when submitting baseline and update schedules. Ultimately, this improves the value of a construction schedule as both a planning and

performance monitoring tool. The following guideline can be used to promote the inclusion of technical attributes within the schedule.

- Project schedulers must have a sufficient level of experience (e.g., 5 years of construction scheduling experience) in order to improve the overall quality of the schedule.

- Each activity shall be assigned Activity ID, Activity Description, Original Duration, Remaining Duration, Percent Complete, Early Start and Finish Dates, Total Float, Budgeted Quantity and Unit of Measure.

- A written narrative describing "changes made to the schedule and the overall impacts to the project" should accompany each update schedule submittal (Winter 2008)

- All float is considered a project resource available to all parties as needed. Float is to be maintained in accordance with the critical path methodology.

- No negative float is permitted in the baseline schedule.

- The schedule shall be time-scaled network logic diagram which encompasses the project's entire scope of work. The schedule shall include sufficient detail as to allow day-to-day monitoring of construction operations.

- Set an activity duration limit based on project-specific characteristics.

- Each activity shall have a unique activity description.

- The first activity and the last activity are the only activities permitted to utilize an open-ended logical relationship. All other activities shall maintain start and finish relationships.

- Excessive use of predecessor and successor relationships is not permitted. Set a limit of relationships based on the complexity of the project.

- Correct the logic of all out-of-sequence activities when submitting update schedules.

- Contract milestones such as Notice to Proceed, Substantial Completion, and Final Acceptance shall be the only permitted constraints within the schedule unless otherwise approved.

- When changes to the work occur, such as additional scope requested by the owner or contractor's change to construction sequence, submit a narrative detailing the impact to the schedule.

- When delays occur that exceed an assigned duration, submit a narrative detailing the reasons for the delay and the plan to regain lost schedule progress.

4.3 Chapter 4 Summary

Chapter 4 explored the various technical attributes associated with a construction schedule including baseline compliance, float and criticality, constraints, and logic. Additionally, technical attributes are explained in terms of PPI. Finally, specification language was provided for the improvement of contract specifications pertaining to technical attributes.

CHAPTER 5

THE PROJECT STATUS REPORT

Once PPI are calculated and verified, they are documented in the Project Status Report (PSR) and delivered to project personnel and other stakeholders for the purpose of making informed project-related decisions. The PSR is an organized document, which allows project personnel to efficiently analyze PPI in one location. "Ideally, during the planning stages of the project, stakeholders participate in a facilitated discussion to prioritize project cost, schedule, quality, safety, and other goals, thus defining project success" (Nalewaik and Witt 2009). With success predefined, the PSR serves as effective means of monitoring progress and performance, as well as determining the project's degree of success. Therefore, not only does the PSR assist in aligning project goals during construction, it also helps determine whether the project is successful.

5.1 Reporting Metrics

On any given project there are many stakeholders: contractors, engineers, managers, financiers, owners, politicians, and others. As such, "the ideas and expectations of a successful project are often subjective, implicit and contradictory" (De Ridder and Vrijhoef 2005). In order for the PSR to be effective, it must be easily understood by a wide array of people and institutions. Therefore, the following considerations are taken to maximize the usability of the PSR (Rahbar 1990).

- Who are the primary users of the PSR?

- What level of familiarity do the end-users of the PSR have with PPI?

- How accurate are the PPI presented in the PSR?

- What do the users of the PSR expect to gain from using it?

- What actions are available or required based on the contents of PSR?

- How frequently is the PSR produced?

- What defines a successful project?

5.2 Project Status Report Components

The PSR is comprised of the PPI discussed herein, as well as other pertinent project contract data. Only the crucial elements of each PPI category are selected to be presented in the PSR. Additionally, a Status Narrative is provided to highlight critical information pertaining to the project such as delays and cost over runs, or simply to report successful execution. The Status Narrative also includes a color-coded indication bar to quickly determine the need for additional assessment. The following sections focus on the integration of PPI into the PSR. Following these sections, Figure 5.1 is an example of the PSR.

5.2.1. Contract Elements

In addition to PPI, the PSR lists key cost and schedule elements derived directly from the contract documents. These baseline values define the project's budget and schedule goals. In many ways, the overall success of the project is based on how closely the project is delivered to these budget and schedule goals. During project execution, these values may change as scope is added to the project. For instance, a change order may add both budget and time to the contract thus increasing the Committed Contract Value and Contract Time.

Original Contract Value

The Original Contract Value is the planned cost of construction. Depending on the type of delivery method, it may be synonymous with the contractor's bid price.

Approved Changes to Date

Approved Changes to Date is the sum of all changes that result in money added to the contract. For instance, when work scope is added to the project, the cost to execute additional work is added to the Original Contract Value.

Committed Contract Value

Committed Contract Value is the current value of the construction project, which is the sum of the Original Contract Value and the Approved Changes to Date.

Cost Incurred

Cost Incurred is the total amount of money expended-to-date on the execution of the project.

Notice to Proceed

Notice to Proceed is the date at which time the contractor can begin work on the project.

Contract Time

Contract Time is the original or planned amount of time to complete the project, which is typically denoted by work days or calendar days.

Days Added

Days Added is the amount of time added to the contract as a result of changes. For instance, when work scope is added to the project, the time to execute additional work is added to Contract Time.

Contract Completion Date

Contract Completion Date is the date on which the project must be complete. It is calculated by adding Contract Time and Days Added to the Notice to Proceed date.

5.2.2. Earned Value

PPI produced by an EVMS are indicative of both cost and schedule. Perhaps the most prominent PPI resulting from EV analysis are Estimate at Complete (EAC) and Time Estimate at Complete, EAC(t). These metrics indicate how much the project will cost and when the project will finish, crucial metrics for all project personnel. Recall, EAC(t) is predicted by four separate earned value analyses: traditional earned value method, planned value method, earned duration method, and earned schedule method. Ideally, project personnel calculate this metric using each of the four methods, monitor and compare the metric over a period of time, and determine which method produces the most accurate prediction of EAC(t). As described in Chapter 2, some EV methods are more accurate than others at specific points in the project life cycle. As such, the most accurate EAC(t) forecast should be presented in the PSR. Alternatively, the Project Status Report may present a range of dates indicating when the project is likely to finish based on the results of all four prediction.

5.2.3. Resources

Resource utilization graphs are instrumental PPI in that they illustrate resources necessary to execute the project in an intuitive bar chart. The progress resource utilization graph is perhaps the most informative PPI, as it compares baseline or committed resources to actual resource utilization in a given time period. In a glance, project personnel can determine whether the contractor is utilizing the number of resources committed by the baseline schedule. This is especially useful when analyzing a specific scope of work for which a particular resource is critical to a timely completion.

Resources can also be illustrated on a global project scale. For instance, all equipment or labor resources can be depicted collectively on the same bar chart. On a single bar chart, all planned equipment (or manpower) is compared to all equipment (or manpower) that is actually being utilized in a given time period. This provides project personnel with an overview of the

resources that are planned for a given time period, which is indicative of the amount of planned work and the level of oversight required to manage construction activities.

In addition to the resource utilization graph, there are two areas dedicated to discussing pertinent resource information. The Resource Narrative is intended to discuss resources that are currently performing work on the project, changes to planned resources, or resource-driven solutions to project issues. The Critical Resource section is intended to identify the critical resources, which are those resources driving the critical path. By identifying these resources, project personnel know which resources to closely monitor, as adjustments to these resources may impact project progress.

5.2.4. Technical Attributes

The PSR presents PPI pertaining to baseline dates compliance, float, criticality, constraints, and logic. Similar to a report card, the PSR includes PPI related to technical attributes that "grade" a project on its adherence to the baseline schedule (original plan). However, there is currently no industry standard that details how well an update schedule must comply with the baselines schedule, how much float is permissible, or how many critical activities are allowed in a baseline schedule. The tolerance (or red flag value of technical attribute PPI must be evaluated on a project by project basis.

THE PROJECT STATUS REPORT

PROJECT NAME:		CONTRACT #	DATE:

CONTRACT FINANCIAL ACTIONS	CONTRACT SCHEDULE MILESTONES	STATUS NARRATIVE
Original Contract Value	Notice to Proceed	
Approved Changes to Date	Contract Time	
Committed Contract Value	Days Added	
Cost Incurred	Contract Completion Date	

EARNED VALUE ANALYSIS

PV $1,500,000
EV $1,245,393
AC $1,399,464

PV, FCST, EAC, BAC, AC, EV

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

TRADITIONAL EARNED VALUE	
EAC	EAC(t)
CV	SV
CPI	SPI

PLANNED VALUE
EAC(t)

EARNED DURATION
EAC(t)
TCSPI

EARNED SCHEDULE
EAC(t)
SV(t)

RESOURCE UTILIZATION

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

RESOURCE NARRATIVE

CRITICAL RESOURCES

TECHNICAL ATTRIBUTES

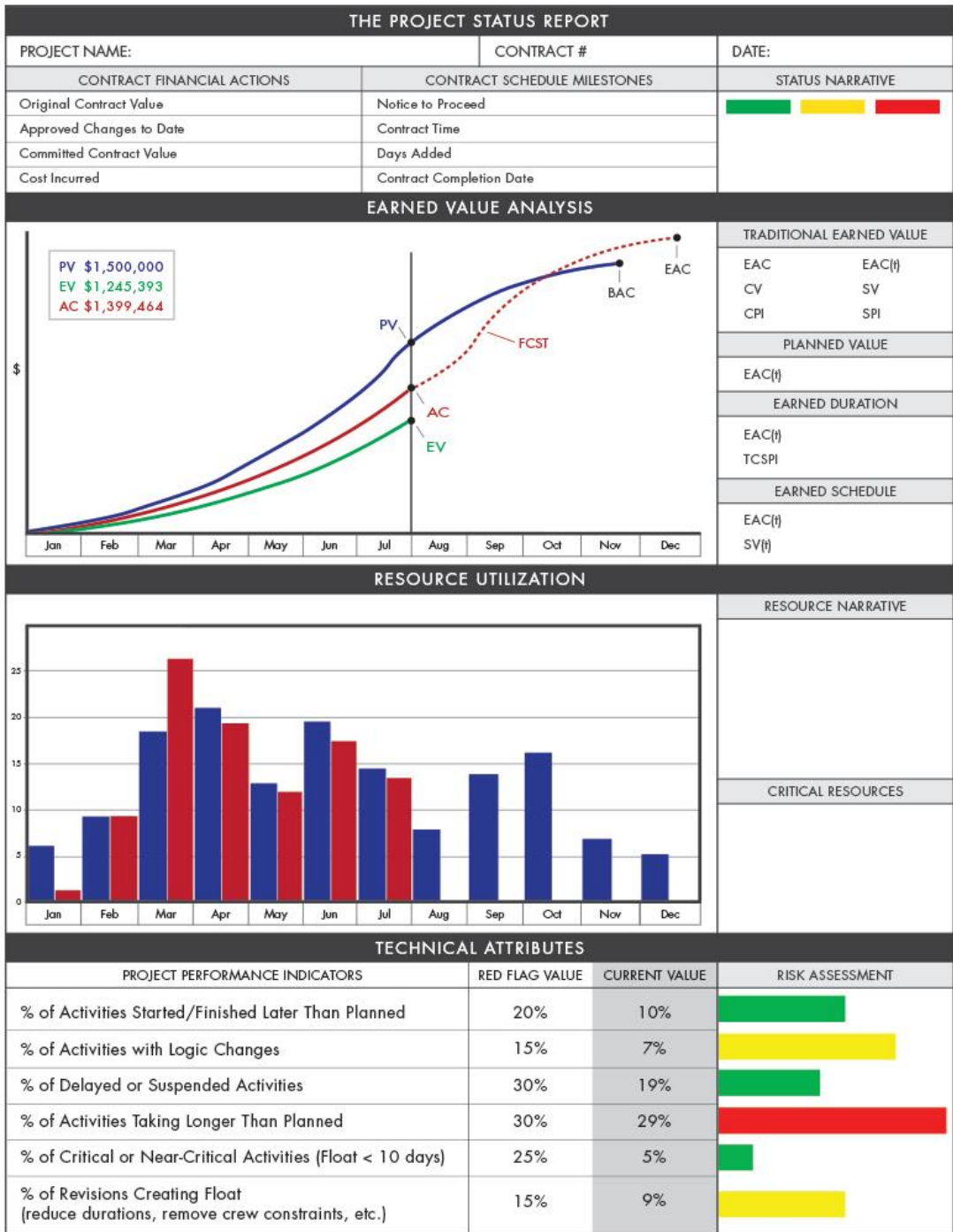| PROJECT PERFORMANCE INDICATORS	RED FLAG VALUE	CURRENT VALUE	RISK ASSESSMENT
% of Activities Started/Finished Later Than Planned	20%	10%	
% of Activities with Logic Changes	15%	7%	
% of Delayed or Suspended Activities	30%	19%	
% of Activities Taking Longer Than Planned	30%	29%	
% of Critical or Near-Critical Activities (Float < 10 days)	25%	5%	
% of Revisions Creating Float (reduce durations, remove crew constraints, etc.)	15%	9%	

Figure 5.1: The Project Status Report

5.3 Chapter 5 Summary

Chapter 5 detailed how PPI are presented in the Project Status Report (PSR). This chapter also examined the criteria associated with reporting metrics for the purpose of building and effective report. Finally, this chapter introduced the PSR, a single-page document that is utilized to efficiently monitor construction projects.

CHAPTER 6

CASE STUDY

6.1 Introduction

Over the course of several years, the project monitoring principals detailed in this thesis were utilized to analyze a large roadway construction program consisting of five primary construction schedules, each exceeding one thousand activities. The project controls techniques performed during construction and lessons learned collected post-construction led to the development of the PSR introduced in this thesis. The following sections detail how the principles discussed herein were a direct result of the project's overall success.

6.2 PPI in Action

6.2.1. Earned Value

The traditional earned value method was utilized during two project phases to assess the status of the project. During the pre-construction phase, earned value techniques were employed to help assess the feasibility of the project finishing within its contractual financial and schedule limits. Upon review of the Budgeted Cost of Work Scheduled (BCWS) curve provided by the contractor, project personnel performed an independent assessment by deconstructing the cost and scope elements of the baseline schedule. The project team developed a forecast (FCST) curve which predicted the project would finish both behind schedule and over budget, as detailed in Figure 6.1. In order to return the project within its contractual financial and schedule goals, project personnel employed value engineering and cost savings techniques

including specifications modification (e.g., type of light source, depth of asphalt versus concrete, etc.), scope reduction, and phasing modification (e.g., optimized traffic control plans) that greatly reduced both the Estimate at Complete (EAC) and Time Estimate at Complete (EAC(t)).
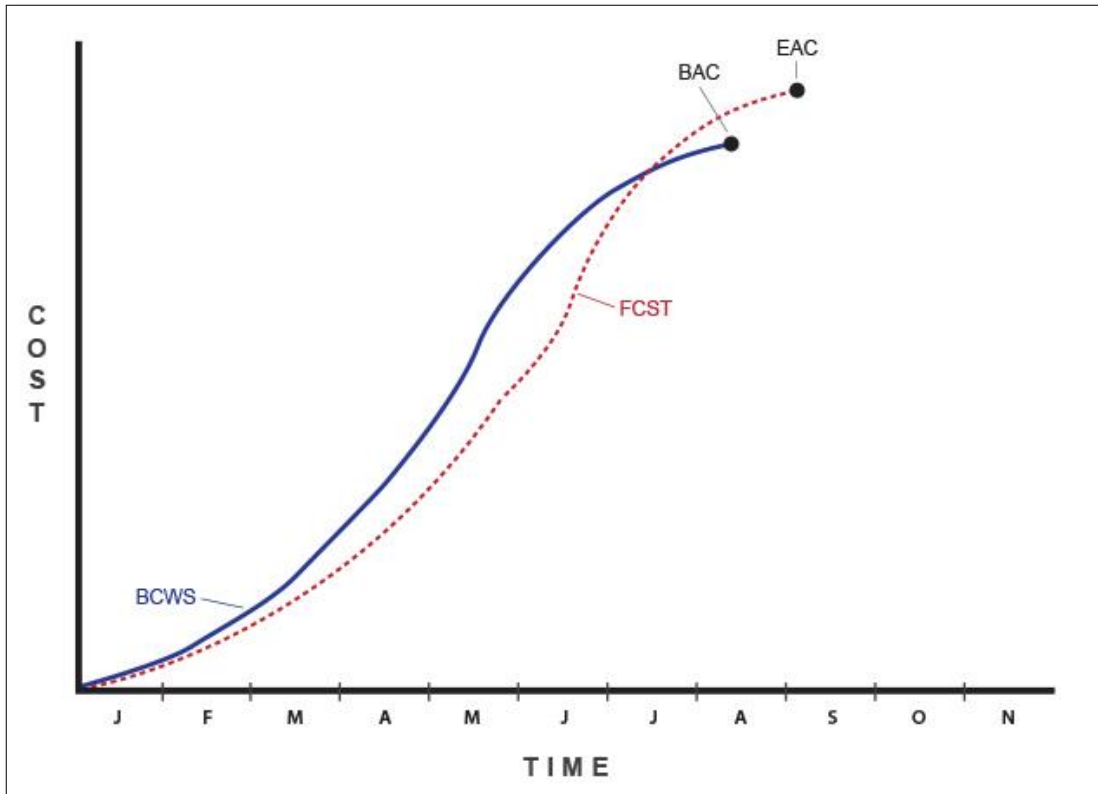
Figure 6.1: Re-forecasted BCWS Curve

During construction, the traditional earned value method was employed to determine the project's financial and temporal status. Monthly reports were generated to assess the owner's financial exposure, which improved their awareness of risk and ability to act accordingly. Upon receipt of monthly schedule updates which included actual project costs and start/finish dates, EV curves were updated for the assessment of forecasted costs and periodic financial responsibilities, as well as the project's anticipated completion date.

Time Estimate at Complete, EAC(t)

To predict when the project completion date, project personnel utilized the traditional earned value duration forecasting equation:

$$EAC(t) = AT + \frac{BAC - EV}{Work\ Rate}$$

Eqn. 6.1

In order to validate the benefit of predicting EAC(t) using traditional earned value, Figure 6.2 illustrates EAC(t) as a function of the project's actual completion date. It compares the contractor's planned EAC(t) per the update schedule against the EV-generated EAC(t). EAC(t) was measured at 20% time complete intervals for a total actual project duration AD of 720 days.
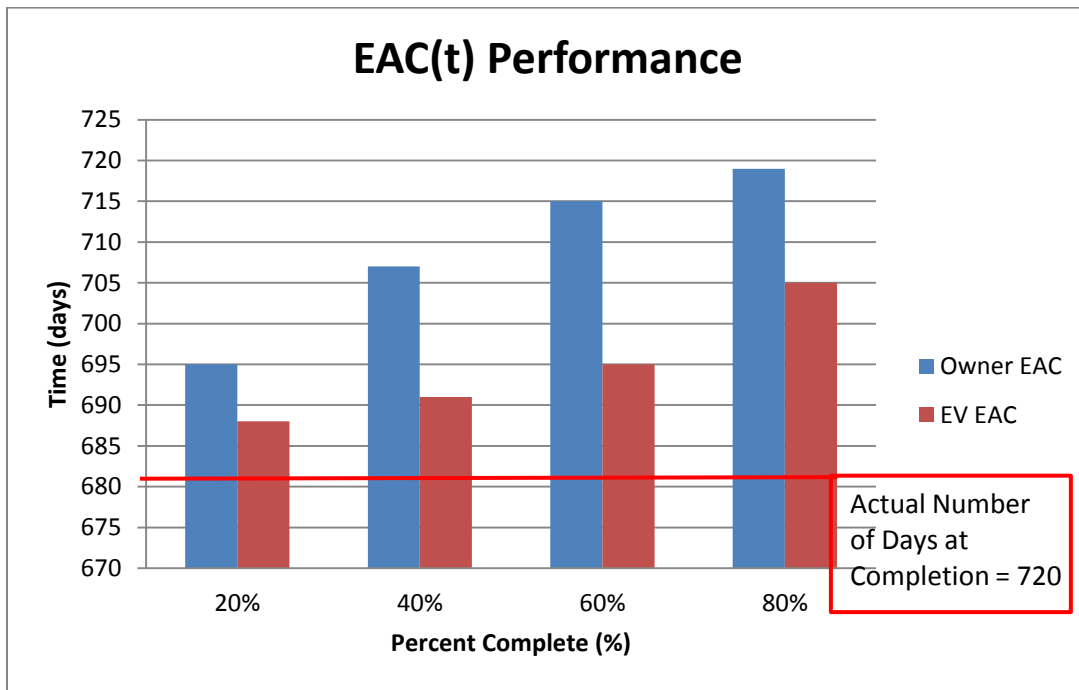

Figure 6.2: EAC(t) Accuracy Comparison

Table 6.1 examines the percent difference between the contractor's and EV-generated EAC(t) values versus the actual project duration AD. It is evident across the entire duration of the project that the EV-generated EAC(t) was a more accurate prediction of the actual project

duration. On average, the EV-generated EAC(t) provided results that were 3% more accurate than the contractor's predicted EAC(t). One important lesson learned during this case study was the need to more accurately assess the project's EAC(t), which resulted in the inclusion of advanced earned value metrics (Planned Value, Earned Duration, Earned Schedule) in the Project Status Report.

Table 6.1: EAC(t) Performance Data

Interval	Contractor EAC(t)		EV EAC(t)	
	Days	% Diff	Days	% Diff
20%	780	8.33%	766	6.39%
40%	789	9.58%	762	5.83%
60%	769	6.81%	752	4.44%
80%	755	4.86%	732	1.67%
Average	-7.40%		-4.58%	

Estimate at Complete (Cost), EAC

The Earned Value Management System utilized on this project also forecasted the Estimate at Complete in terms of cost, EAC, using the following traditional earned value formula:

$$\text{EAC} = \text{AC} + \frac{BAC - EV}{CPI \text{ or } SPI \text{ or } SCI}$$

Eqn. 6.2

As illustrated by Figure 6.3, EAC was assessed using Eared Value analysis and compared against the committed contract value, which was the owner's method of determining the cost to complete the project. The current contract value includes the original contract value ($680M) plus the approved changes to date ($20M). EAC was measured at 20% time complete intervals for a total actual project cost AC of $700M.
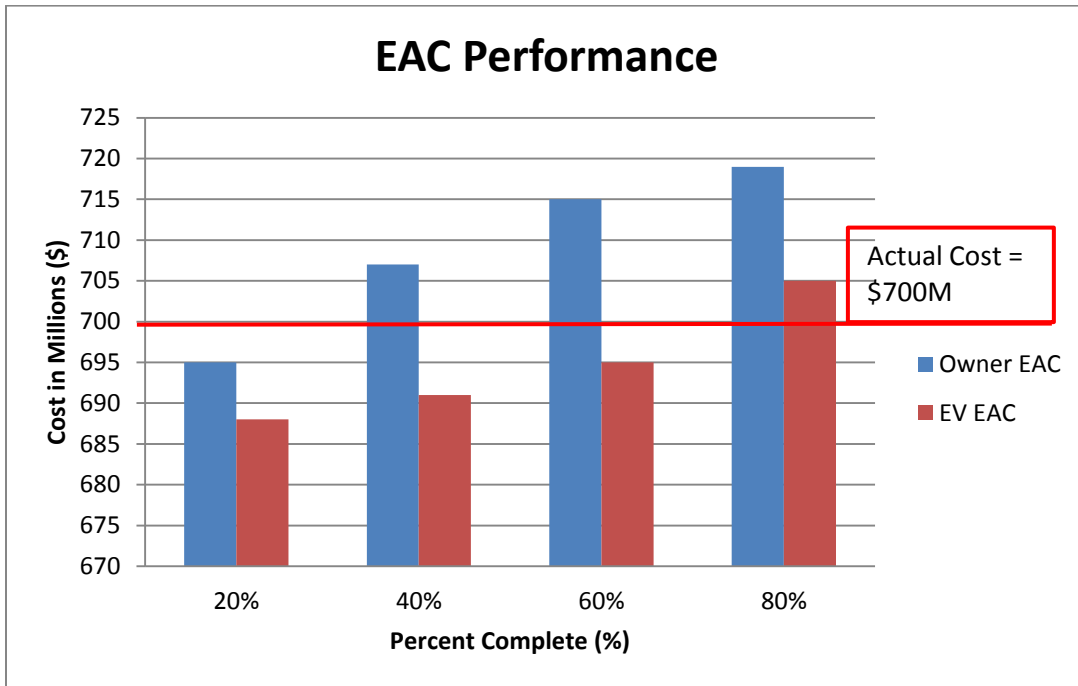
Figure 6.3: EAC Accuracy Comparison

As illustrated by Table 6.2, the EV-generated EAC value produced a more accurate prediction of the project's cost at complete. Over the entire course of the project, this improved the owner's ability to make smarter financial decisions. Equipped with accurate financial data, the owner pulled only necessary money from investments, leaving the rest to accrue interest.

Table 6.2: EAC Performance Data

	Owner EAC		EV EAC	
Interval	$	% Diff	$	% Diff
20%	695	0.71%	688	1.71%
40%	707	-1.00%	691	1.29%
60%	715	-2.14%	695	0.71%
80%	719	-2.71%	705	-0.71%
Average	-1.29%		0.75%	

Resources were continually monitored on the project in both the office and the field. In the office, resource utilization graphs were generated from the baseline schedule and each monthly update schedule. These graphs detailed the planned and current utilization of each crew working on the project. Using utilization graphs as a guide in the field, resources were field-verified and compared against the documented resources in the schedule. In this way, the schedule could be verified as an accurate representation of field activities.

As detailed in Figure 6.4, this project resource was analyzed because the contractor was not meeting its commitment per the baseline schedule. The yellow bars indicate the contractor's planned or budgeted resources, while the blue bars indicate the contractor's actual resource utilization. In the months of June and July, the contractor actually utilized only half of its planned resource. As a result, the activities that were driven by this resource fell behind schedule.
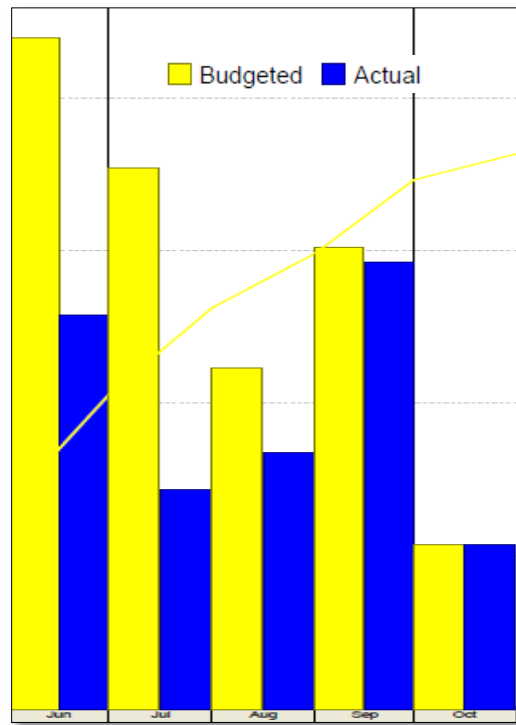

Figure 6.4: Progress Utilization Resource Curve

In efforts to return the schedule to its scheduled path, a "what-if" analysis (Figure 6.5) was performed to gain perspective of how additional resource might impact these activities. Additional resources were loaded into the activities affected by the aforementioned resource, and the schedule was recalculated to measure impact. The additional resources resulted in a considerable improvement in production thus shortening the activity duration. This information was shared with the contractor for the purpose of acquiring additional resources to gain time on the schedule. As a result of resource analysis, the contractor agreed to mobilize additional resources which helped these activities to finish within the planned time period.
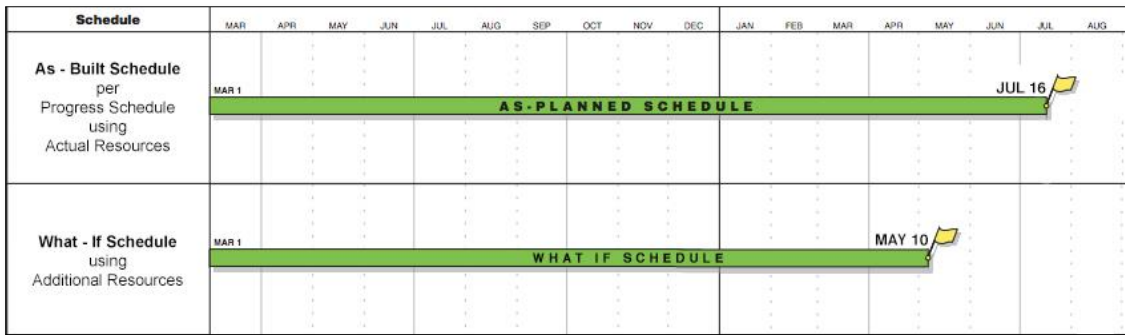

Figure 6.5: What-If Resource Analysis

6.2.3. Technical Attributes

Upon receipt of the baseline schedule, a thorough analysis of technical attributes was conducted to determine whether the schedule met the schedule requirements detailed by the contract specifications. This check was performed to ensure that the schedule was able to provide PPI while meeting contractual obligations. Furthermore, this baseline technical attribute analysis was conducted to identify scheduling errors and inconsistencies in terms of logic and coding, as well as spot any problematic areas in terms of constructability. A common result of the baseline technical attributes analysis was the rejection of the baseline schedule due to insufficient information (resources, activities codes, etc.) and/or lack of adherence to contract specifications. This ultimately led to better schedules producing more accurate PPI. Table 6.3 summarizes the number of technical attribute checks that were performed for each baseline

schedule. The following checks were examples of those performed during the baseline schedule technical attributes analysis.

- Project Calendar Check determines the number of calendars utilized in the schedule and the work times associated with each calendar. Each calendar should then be examined for compliance to the contract documents.

- Milestone Check determines the number of activities set as milestones. Depending on the specification, the contract may limit the use of milestones to specific activities listed in the contract.

- Lags and Leads Check examines lag and lead times associated with each activity. Lag or lead times exceeded 5 days should be individually investigated.

- Predecessor and Successor Check ensures that all activities have a start and finish relationship, which is required by most scheduling specifications.

Table 6.3: Baseline Schedule Technical Attributes Analysis Summary

Baseline Schedule Technical Attributes Review	
Description of Technical Attribute	Number of Independent Analysis
Statistical Review	24
Activity Checks	41
Activity Steps Checks	16
WBS & Code Checks	11
Relationship Checks	27
Constraint Checks	11
Expense Checks	10
Resource Checks	10
Memo Checks	6
Attached Document Checks	3
Issue Checks	2
User-Defined Field Checks	11
Upper-DCMA Agency Checks	12
Upper-Level Checks	1
Total Checks	185

During construction, technical attributes were analyzed on a monthly basis. Each month, this data provided an informative overview of the schedule's progress and performance. The data produced from this analysis was, in large part, generated by comparing the monthly update schedule to the previous update and/or baseline schedule. In doing so, project personnel analyzed the differences and similarities between successive schedules to determine what occurred during the update period and whether the project was achieving its planned performance. Table 6.4 summarizes the number of technical attribute checks that were performed during each progress schedule review. The following checks were examples of those performed during the progress schedule technical attributes analysis.

- Modified Duration Check identifies activities with original durations that were modified. Original durations should not be modified without consent, as they were approved in the baseline schedule.

- Activity Code Check identifies activities with activity codes that were modified. Modified activity codes should been individually investigated, as these codes potentially change the nature of the activity.

- Diminishing Progress Check assess the performance of the activity relative to its past performance. The Contractor should provide a definitive reason as to why progress is negative.

- Change of Actual Dates Check identifies activities with actual dates that were modified. Changing actual dates once a schedule is accepted may invalidate that schedule since the as-built information was modified.

Table 6.4: Progress Schedule Technical Attributes Analysis Summary

Progress Schedule Technical Attributes Review	
Description of Technical Attribute	Number of Independent Analysis
Statistical Review	12
Activity Checks	43
Activity Steps Checks	12
Activity Code Checks	3
Relationship Checks	12
Constraint Checks	11
Expense Checks	10
Resource Checks	18
Memo Checks	5
Attached Document Checks	6
Issues Checks	7
User-Defined Field Checks	31
DCMA Agency Checks	13
High-PASEG Agency Checks	4
High-Level Checks	1
Total Checks	188

By analyzing the schedule's technical attributes, project personnel were able to identify the root cause and effect of a delay that resulted in a claim raised against the owner. As detailed in Figure 6.6, the activities associated with this claim were isolated in a schedule fragnet, and a "window" delay analysis was performed. Using this method, project personnel identified the existence of a concurrent delay caused by the contractor, resulting in a non-compensable time extension. As a result, the contractor's claim was invalidated which cleared the owner's responsibility to compensate the delay costs.
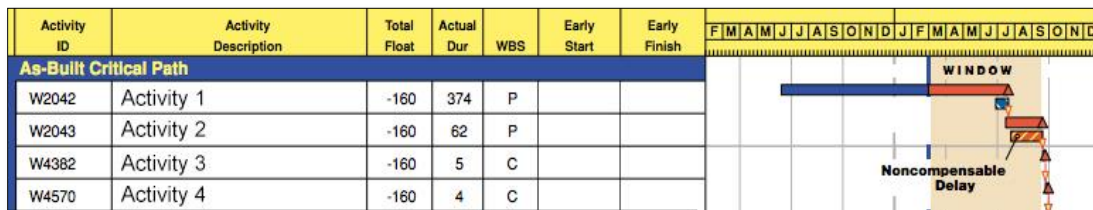

Figure 6.6: Schedule Fragnet for Delay Analysis

6.3 Chapter 6 Summary

A case study was conducted to validate the benefits of the PPI presented in this thesis. The principles presented herein were tested and verified on a major roadway project over the course of several years. The techniques established and lessons learned during this project were incorporated into this thesis for the purpose of developing a construction project monitoring program.

The results of this case study provide significant evidence that the proposed construction monitoring program improves the degree of project success. Specifically, by utilizing an Earned Value Management System, project personnel should expect an increase in the prediction accuracy of project cost and duration. Additionally, monitoring project resources allows for superior control of the project by providing the ability to enforce contractor commitments and realign planned project milestones. Finally, the assessment of technical attributes proved to protect the interest of project stakeholders by acting as a defense mechanism against claims. In all, this monitoring program provided metrics which were indicative of the project's status. Based on these metrics, project personnel made critical decisions that directly impacted the project's bottom line.

CHAPTER 7

CONCLUSIONS, LIMITATIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

7.1 Conclusions

Upon thorough review of applicable Association for the Advancement of Cost Engineering standards, construction scheduling text books, as well as progress and performance monitoring research papers, a need was assessed for the improvement of construction project monitoring. Using both modern software tools and fundamental schedule principles as a guideline, a collection of informative PPI was identified to gain perspective on the status of a project. Additionally, the process by which PPI is extracted from construction schedules was explained in terms of progress and performance. Furthermore, scheduling specification language was examined to promote the ability to contractually obtain PPI. To that end, a Project Status Report was created in order to effectively deliver PPI to project stakeholders for the purpose of making smarter project-related decisions.

7.2 Limitations

The major limitation associated with this thesis occurs in the validation of the Project Status Report as a successful project monitoring tool. It would be difficult to gauge the benefit of the Project Status Report without running a project simultaneously with and without using the Project Status Report. However, the Project Status Report has received much positive feedback from industry professionals indicating that it would be an efficient and effective means of monitoring construction projects. Specifically, construction professionals including resident engineers, cost engineers, as well as designers have indicated that the Project Status Report

produces more information and is better designed than their current method of monitoring project.

<u>7.3 Recommendations for Future Research</u>

Given the rise of software packages capable of advanced CPM scheduling (e.g. Primavera and Microsoft Project) and schedule monitoring (e.g., Acumen Fuse and Schedule Analyzer Pro), it would appear that the future of project and performance monitoring rests in the hands of software developers. Institutions are looking to automate scheduling processes to lower costs and improve simplicity of reporting. However, with the advancement of technology should also come the standardization of scheduling practices and evolution of the scheduling profession. Software automates much of the production of schedule metrics but, in the end, an experienced scheduler is needed to interpret the metrics and guide the decision-making. The principals of scheduling and cost control must continue to evolve with the increasing access to various forms of cost and schedule data.

Additionally, great strides are being taken by companies like Acumen (original developers of Primavera) to incorporate intuitive risk analysis into schedule monitoring. Risk analysis strategies, such as the Monte Carlo simulation, account for the uncertainty and potentially impact of risk event during the course of construction. Presently, project risk analysis is considered a highly complex practice. One of the greatest challenges of risk analysis is the ability to capture representative uncertainty and generate risk inputs. Software packages and standardized risk workshop practices are now driving simplified risk analysis practices. When risk analysis is able to more accurately and readily determine risk exposure, then this data should be incorporated into the Project Status Report. In summary, the following topics are recommended for future research:

- The automation of construction project monitoring
- The integration of risk analysis into the proposed construction monitoring program
- The selection of schedule metrics under the pretense of a project's nature

APPENDIX A

LIST OF ACRONYMS

AACE = Association for the Advancement of Cost Engineering

AC = Actual Cost (=ACWP)

ACWP = Actual Cost of Work Performed (=AC)

AD = Actual Duration

AT = Actual Time

BAC = Budgeted Actual Cost

BCWP = Budgeted Cost of Work Performed

BCWS = Budgeted Cost of Work Scheduled

CPI = Cost Performed Index

CPM = Critical Path Method

CR = Critical Ratio (=CSI=SCI)

CSI = Cost Schedule Index (=CR=SCI)

CV = Cost Variance

EAC = Estimate At Completion (cost)

EAC(t) = Estimate At Completion (date)

ED = Earned Duration

ES = Earned Schedule

ETC = Estimate To Completion (cost) (=PCWR)

ETC(t) = Estimate To Completion (date)

EV = Earned Value

EVM = Earned Value Management

EVMS = Earned Value Management System

FCST = Forecast of Work Remaining

PCWR = Planned Cost of Work Remaining (=ETC)

PD = Planned Duration

PF = Performance Factor

PMI = Project Management Institute

PPI = Project Performance Indicator

PSR = Project Status Report

RD = Real Duration

SCI = Schedule Cost Ratio (=CR=CSI)

SPI = Schedule Performed Index

SPI(t) = Schedule Performance Index at time t

SV = Schedule Variance

TCPI = To Complete Performance Index

WBS = Work Breakdown Structure

APPENDIX B

COMPARISON EARNED VALUE METHODS

Table B.1: Summary of Advanced EV PPI

	Planned Value Method		Earned Duration Method		Earned Schedule Method	
Baseline	SAC	Schedule at completion	PD	Planned duration	PD	Planned duration
Status of the project	PVRate	Planned value rate	ED	Earned duration	ES	Earned schedule
	AT	Actual Time	AD	Actual duration	AT	Actual time
	SPI	Schedule performance index	SPI	Schedule performance index	SPI (t)	Schedule performance index time
	SV	Schedule variance	SV	Schedule variance	SV (t)	Schedule variance time
	TV	Time variance	-	-	-	
	CR	Critical ratio	-	-	SCI (t)	Critical ratio time
	TEAC = AT + TEC		*EDAC = AD + UDR*		*EAC (t) = AT + PDWR*	
At completion indicator	TETC	Time estimate to complete	UDR	Unearned duration remaining	PDWR	Planed duration for work remaining
	TEAC	Time estimate at completion	EDAC	Estimate of duration at completion	EAC (t)	Estimate at completion time
	EAC (t) PV1	Estimate of duration at completion PF = 1	EAC (t) ED1	Estimate of duration at completion PF = 1	EAC (t) ES1	Estimate of duration at completion PF = 1
	EAC (t) PV2	Estimate of duration at completion PF = SPI	EAC (t) ED2	Estimate of duration at completion PF = SPI	EAC (t) ES2	Estimate of duration at completion PF = SPI (t)
	EAC (t) PV3	Estimate of duration at completion PF = SCI	EAC (t) ED3	Estimate of duration at completion PF = SCI	EAC (t) ES3	Estimate of duration at completion PF = SCI (t)
Assessment indicator	-	-	TCSPI	To complete schedule performance index for PD	SPI (t) to go	To complete schedule performance index for PD
	-	-	TCSPI-LRS	To complete schedule performance index for LRS	To complete SPI (t)	To complete schedule performance index for latest revised schedule (LRS)

Table B.2: Summary of Advanced EV PPI with Comments

SITUATION	FORECASTING METHOD			COMMENTS
	Planned Value Method	Earned Duration Method	Earned Schedule Method	
EAC (t) as originally planned	Monitor schedule	-	-	The final project duration will be as planned, regardless of the past performance. This situation may be dangerous, as unattended problems mostly do not resolve themselves ("we'll catch up during the commissioning phase")
PDWR is new	Re-schedule	-	-	The original project assumptions are no longer valid for the remaining work (due to changed conditions). The use of performance indices to predict is obsolete and a new schedule for the remaining work needs to be developed.
PDWR is very high	Re-schedule	-	-	Quantity problems are irreversible and a lot of extra time is needed to fix the problems (occurs mostly in the late project stage). Stakeholders usually lose their interest in the project ("If this project ever finishes, it would be a miracle").
PDWR according to plan	EAC (t) $_{PV1}$	EAC (t) $_{ED1}$	EAC (t) $_{ES1}$	Past performance is not a good predictor of future performance. Problems/opportunities of the past will not affect the future, and the remaining work will be done according to plan.
PDWR will follow current SPI trend	EAC (t) $_{PV2}$	EAC (t) $_{ED2}$	EAC (t) $_{ES2}$	Past performance is a good predictor of future performance (realistic!). Problems/opportunities of the past will affect future performance, and the remaining work will be corrected for the observed efficiencies or inefficiencies.
PDWR will follow current SCI trend	EAC (t) $_{PV3}$	EAC (t) $_{ED3}$	EAC (t) $_{ES3}$	Past cost and schedule problems are good indicators for future performance (i.e., cost and schedule management are inseparable). The SCI = SPI * CPI (schedule cost radio) is often called the critical ratio index.

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BIOGRAPHICAL INFORMATION

Mr. Totin has gained much experience in the civil engineering industry in the areas of program and construction management while focusing on project controls, contract administration, and construction inspection. His background includes scheduling, cost and document control, construction contract administration, claims and delay analysis, project engineering and construction inspection. His project experience ranges from the United States Space Shuttle Program to service roads, bridges, and tollway systems. Mr. Totin has worked closely with program and construction managers, project controls managers, resident engineers, inspectors, general contractors, and project owners. He expects to sit for the Principles and Practice in Engineering Exam for his professional engineer license in April 2013.