University of Alberta

Project Controls for Engineering Work in Practice

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Abstract

Engineering work can account for 10% to 20% of capital project costs, and up to 50% of a project's schedule. The construction industry rigorously implements control techniques to minimize cost and schedule overruns; however, the same cannot be said for controlling engineering work. Over the years, engineering work has proven its susceptibility to cost and schedule overrun, yet controls have not been implemented to the same level of rigor. In practice, engineering work is controlled through techniques such as schedule and accounting summaries and neglects the relationship between cost, schedule and progress. This research aims to improve project control of engineering work in practice by adapting Earned Value Management (EVM) techniques used in construction to the requirements of engineering work. Techniques for EVM baseline development and maintenance, progress measurement, performance analysis, forecasting, and corrective action are customized to the engineering effort and successfully applied on two major engineering projects.

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List of Abbreviations

AC – Actual Cost

ANSI – American National Standards Institute

CII – Construction Industry Institute

EOR – Engineer of Record

EVM – Earned Value Management

EVA – Earned Value Analysis

PV – Planned Value

EV – Earned Value

PMI – Project Management Institute

DOD – Department of Defence

BAC – Budget at Completion

EAC – Estimate at completion

WBS – Work Breakdown Structure

FCAC – Forecasted Cost at Completion

PI – Performance Index

FPI – Forecasted Performance Index

SPI - Schedule Performance Index

CPI – Cost Performance Index

VAC – Variance at Completion

FCI – Forecast Criticality Index

1 INTRODUCTION

Engineering costs on civil construction projects typically account for 10% to 20% of capital project costs (The Association of Consulting Engineers NZ, 2004). The schedule of the engineering/design phase of a project generally dictates the overall project schedule, often accounting for up to 50% of the delivery time. While cost and schedule overruns on capital projects are a reality, research has mainly focussed on controlling the construction portion of the work. Over the years, the engineering effort in design and construction has proven its susceptibility to cost and schedule overrun, and is a contributor to overall project overruns. Current practices in general control engineering costs and schedule through comparison to budget and baseline schedule without clear linkage between effort, progress, and costs. This leads to cost overruns and schedule slippage. This research aims to improve cost and schedule control of engineering work in practice by adapting Earned Value Management (EVM) techniques used in construction to the unique requirements of engineering work. EVM has been successfully applied to construction work, but the adaptability of this approach to controlling engineering work has significant challenges. The key challenges to be addressed are:

- C1. Work-packaging, estimating, and scheduling to create an integrated cost and schedule baseline.
- C2. Determining the proper distribution of effort over time for engineering tasks.
- C3. Tracking and incorporating cost and schedule changes into the EVM baseline.

- C4. Establishing practical methods for measuring progress that encapsulates the entire engineering effort.
- C5. Planning engineering work and measuring progress during the construction phase.
- C6. Correctly allocating actual costs (AC's) that are congruent with progress.
- C7. Prioritizing corrective actions for performance variances.
- C8. Forecasting that accounts for the relationship between cost and schedule unique to engineering work in design and construction phases.
- C9. Gathering the required information to perform EVM in an accurate, efficient, and timely manner.
- C10. Reporting results visually and effectively to various levels of detail.

The key challenge overarching all of these, however, is the efficiency of this system. The effort required for controlling engineering work is under more scrutiny than that required for controlling construction work, because the cost of the engineering effort is significantly less than the cost of the construction effort. Subsequently, the cost of implementing this form of project controls on engineering work should consume less effort than implementing on construction work. To that end, this research places emphasis on developing efficient and practicable solutions to the challenges of implementing EVM on engineering work.

1.1 Background and Problem Identification

Cost and schedule are two of the most important components of a project. A project can succeed or fail based on how these two components are managed. Unfortunately, cost and schedule targets are all too often not met.

Project controls is a term used to describe the processes for controlling the many facets and processes involved in a project including communications, document control, resource management, change management, risk management, contract administration, etc., but perhaps the most important is cost and schedule control.

Implementing proper project controls is a key best practice to help projects achieve cost and schedule targets (Anderson & Tucker, 1994). The Construction Industry Institute (CII) emphasizes the major role that project controls play in the success of projects. Project controls function as the "eyes and ears" of management at all levels on the project and keep the client informed on the status of the bottom line — cost and schedule (Construction Industry Institute, 1986).

Construction Industry Institute (1986) suggests that the key benefits of a proper project controls system are that it:

- Documents the project plan and actual performance.
- Identifies problem areas and trends.
- Is a communication tool.
- Allows project management to keep a handle on the work.
- Feeds into a historic database for future planning of comparable work.

But in order for these to be realized, project controls must start at the planning phase of the project, encompass all related work, and be treated as an integral part of project management.

An often overlooked component of a project controls system is its ability to foster accountability and transparency: accountability for budgets to be met not only at the end of the project, but throughout the project, and accountability for schedules to be adhered to not only at the end date of the project, but at all interim milestones as well. It creates transparency in the period-to-period productivity and expenditure not only at the project level, but also for all individual work-packages. It fosters transparency in the internal project team relationships and relationships with the client/owner. It is built on the premise that accountability and transparency incite higher performance (Sullivan & Michael, 2011).

Project Controls on Construction Projects

The construction industry has a long history of using project controls systems to plan, track, and measure cost and schedule performance. Work is broken down into manageable packages, budgets and schedules are set, and then construction progress is measured periodically and compared to original plans. A widely used technique to facilitate this control is EVM. Originally coined “Cost/Schedule Control Systems Criteria (C/SCSC),” it was first introduced to the project management environment in 1967 by the US Department of Defense (Fleming & Koppelman, 2006). Its appeal is owed to its simplicity, integration of time and cost performance measures, and ability to provide early warning signs on cost performance (overrun or under run) and schedule performance (ahead or behind) (Vanhoucke, 2009).

In construction, EVM has become a standard for both contractors and owners to control cost and schedule. The Department of Defense has issued an EVM implementation standard for use on it projects. Standards have been issued by American National Standards Institute (ANSI) and Project Management Institute for EVM implementation on projects including construction.

Construction projects are not just comprised of construction work. They invariably have an engineering component that generally accounts for 10% to 20% of the overall costs (The Association of Consulting Engineers NZ, 2004). In fact, construction projects are generally initiated through an engineering phase where project feasibility is assessed, concepts are developed, and designs are created. The construction phase is only one component of a project, albeit the most expensive, and even this phase involves significant engineering effort to monitor, inspect, and manage the work.

Control of engineering work has generally been relegated to simple controls such as progress report, master schedule, detailed 4-week look-ahead schedule, and monthly accounting summaries (Chang & Ibbs, 1998). These documents provide summary-level insight into what has happened to date, what is planned, and where costs have been incurred. They provide a relatively subjective overview of progress. They do not integrate cost and schedule, or measure physical progress. They do not provide a structured or analystical view of performance, nor do they offer substantiated forecasts of project end results. They do not provide a reliable framework for controlling individual project components, nor do they offer adaquate prioritization of management attention. With these forms of project controls, the owner and management team are more susceptable to being left in the dark, or being caught by surpise when a budget is overrun, or a schedule slips. Often, end results of the project are not exposed until the project is nearing completion.

With the current control measures, Chang and Ibbs (1998) point out that schedule and cost measures were not well used in controlling the engineering effort. Cost is only controlled through monthly invoice approval, and schedule had no discussion of problems or corrective actions.

That being said, a gap exists between the form of project controls implemented on construction work versus that used to control engineering work during design and construction. Project controls for engineering work historically have not been implemented with the same rigor and detail than they have been for construction work. No specific standards exist for implementing EVM on engineering work. Research has been conducted in this area, primarily in the late 1980s to 1990s, to address this, but the transfer of these techniques into practice has been slow and in some cases non-existent (Chang, 1997; Eldin, 1988).

Controlling Engineering Work

It may be said that engineering effort is not controlled with the same level of rigor because the cost of engineering work is minimal compared to construction work, and as such, extensive effort expended on controlling this work is not justified. Another reason may be that engineering effort is on a smaller scale than construction work effort. Perhaps the gap exists between construction project controls and engineering project controls because controlling engineering work is generally more difficult than construction work due to:

- tasks being more difficult to quantify and track between start and completion;
- the presence of more parallel/overlapping tasks;
- the fact that many different disciplines are involved; and
- the tendency for scope to be less defined during the design phases of the work, and therefore, less able to be controlled (Construction Industry Institute, 1986).

Regardless of the reason for project controls' slow implementation on engineering work, the question still exists as to whether engineering work warrants more rigorous project controls.

Research has focused attention on managing construction work over design work, primarily due to the vast cost difference. However, the following literature demonstrates the importance of controlling engineering work:

- A well cited study concerning engineering work found that 33% of architectural and engineering projects missed cost and schedule targets (Anderson & Tucker, 1994).
- On major projects, the design effort can amount to considerable cost and certainly warrants proper project controls (Eldin, 1991).
- The design effort has a high level of influence on project costs (Barrie & Paulson, 1992).

- On four environmental and engineering projects in the study by Chang (2002), costs increased on average by 9.2%, and schedule increased by 23.3%.
- A "lack of timely, clear, and a readily available performance measurement" (P. 249, Sullivan & Michael, 2011) is cited as a key reason for poor quality and overrun issues in the design industry.
- A survey completed by the Construction Management Association of America (CMAA) found 50% of design efforts finished behind or significantly behind schedule (CMAA, 2004).
- A study by the CII states that, "…a project must have a formal project controls system if there is to be success, and that system must encompass the engineering effort" (P. 1, Construction Industry Institute, 1986).

Through the research conducted on the area of project controls on engineering work, and the author's experience, there is evident merit in improving the practical implementation of project controls on engineering work in design and construction.

1.2 Research Methodology

The formal research approach used to undertake this study is based on a mixed methods approach (Deborah & Toole, 2009; Green et al., 2009). The research has dual focuses: (1) to further and broaden academic research in the area of project controls; and (2) to solve a problem in industry regarding cost and schedule control of engineering work. In order to satisfy both focusses, the research is conducted through an interactive process of establishing the grounded theory through literature reviews, and refining this through practitioner input and application in practice (Glaser & Strauss, 1967).

The use of practitioner input has long been practiced in construction management research. A strong link with industry and full understanding of day-to-day challenges faced by practitioners are essential to meaningful research in this area (Green et al., 2009). This approach is well suited for the sense-making approach where academics and practitioners actively work to make sense of otherwise ambiguous phenomena. Research develops theory and practitioners comment on the validity and usefulness of the insights. Research works best when these roles are interchangeable (Green et al., 2009).

The research conducted in this study utilizes an ethnographic research methodology where the researcher is immersed in the research setting (Rooke, 1997). In this approach, theory can be intimately combined with practice at every step of the research. Green et al. (2009) states that there is no harsher test for the validity of research findings than to subject them to the critical scrutiny of practitioners embedded in the research context.

A mixture of techniques are used to gather data and gain feedback on the effectiveness of the proposed techniques, including formal and informal interviews, field observation, analysis of in-house documents and archives, formal workshops settings, and informal interactions between the researcher and practitioners. Case studies are also used to validate and refine the research.

Research Plan

The plan used to structure the research and conduct this research is as follows:

- Review what is done on construction projects for project controls through industry standards and best practices.
- Review what is used to control engineering work in literature through literature reviews.
- Understand what is used for controlling engineering projects in practice via a review of project documents and informal communications on the projects through emails, phone conversations, and informal interviews with project managers and owners.
- Identify the gaps between project controls for construction versus project controls for engineering work in practice, and expose any barriers between adopting the construction project controls for engineering work.
- Develop an initial approach for project controls for engineering work and implement on real projects in practice. Document these as case studies.
- Refine the approach for project controls based on lessons learned and results from the case studies, and form into the proposed approach for controlling engineering work in design and construction.

In developing the proposed approach, the factors that dictate which techniques and components will be used is based on the end goal of the project controls system — effectiveness and efficiency: effective enough to satisfy the owner's needs for transparent performance metrics, reliable forecasts, and successful conclusions, yet practical enough to break through the barriers that have inhibited the use of this form of project control for engineering work in the past.

1.3 Thesis Structure

The research presented in this document is structured into three main sections:

- Project Controls Literature Review: a review of the current practice standards for project controls in construction, and detailed review of current practices for controlling engineering work. This includes a review three recent engineering projects to determine the current state of project controls for engineering work in practice.
- Proposed Project Controls Approach for Engineering Work: a discussion of the proposed approach developed based on a combination of literature review, transfer of existing practices for construction work to engineering work, and results of implementation and refinement of the proposed approach on two major engineering projects.
- Implementation of Proposed Approach: a discussion of two case studies used in the development of the proposed approach for controlling engineering work during design and construction.

The sub-chapters for the proposed controls system will follow a common structure, congruent with the components of a proper project controls system, in order to provide continuity throughout the document. These chapters are: Baseline Development; Baseline Maintenance; Progress and Earned Value (EV); AC; Performance, Forecasting and Corrective Action; and Reporting and Decision Making.

2 PROJECT CONTROLS LITERATURE REVIEW

2.1 Construction Project Controls

Project control systems are utilized throughout the construction industry in order to manage projects in a consistent and organized fashion. Predominant functions of a project controls system within the construction industry are: measuring current performance and predicting future performance within a project, and indicating where corrective action is needed and where deviations are minimal enough to ignore. From an owner's perspective, an accurate project controls system ensures payment to contractors is only made for work that is completed (Nasser, 2005). On the contractor's side, many utilize project controls systems for tracking and optimizing resource utilization in terms of current usage as well as forecasted capacity (Hammad A. , 2009). In tight economic times it is critical for a construction company to optimize its resources by knowing what jobs to bid on and when the required resources will be available. This necessitates forecasting techniques that are reliable (continually produce consistent results), precise (capable of forecasting with a narrow degree of error), and accurate (produce results that are sufficiently close to reality).

Project controls systems are implemented on construction projects for many reasons. They are used in updating project performance status; identifying deviations from the plan as early as possible in order to make timely corrective action; filtering and prioritizing deviations to allow only the significant issues to trickle through to the decision maker; and forecasting future project performance in terms of remaining resource requirements, cost at completion, and final project duration.

A project controls system is built on the premise that breaking a project into smaller, more manageable parts and then controlling those individual parts will ultimately allow for control of the project as a whole. The tracking of cost and duration of a project can be a difficult task primarily due to the interrelated and time-dependent nature of cost, schedule, and progress. This necessitates control that is integrated between the three (Eldin, 1988). A project controls system must encompass the planning, scheduling, monitoring, reporting and analysis, forecasting, and historical data collection of a project to be considered a complete system (Construction Industry Institute, 1986). In this way, the system integrates project budget, schedule, and progress measurement, the three corner stones of project controls (Eldin, 1991).

The Defense Contract Management Agency – DoD (2006) suggests that key attributes of effective project controls are not only the integration of cost, schedule, and progress, but also:

- visible and apparent management support,
- timeliness of analysis,
- focus on significant variances and developing trends,
- forecasts based on past performance,
- multi-functional team approach to analysis of results, and
- management focus on developing credible corrective actions.

Once a project controls system has the proper support and management attention, it can follow a repetitive and structured process similar to that defined by Nasser (2005):

- establish baseline,

- collect project data,
- evaluate performance by comparing data to baseline,
- forecast performance,
- analyze variances,
- implement corrective actions, and
- improve performance.

Although most cost and schedule project controls system are based, in one form or another, on the fundamentals of EVM, there are a variety of techniques and permeations.

Janamanchi and Burns (2005) approached project controls through the use of system dynamics. They state that managing complex projects requires controls and models able to account for interdependencies of different parts of the system (project). This requires a holistic approach and system dynamics provides this. System dynamics are used by project managers for estimating, risk analysis, and progress monitoring and diagnostics.

The authors developed a model to simulate the impact of changes, size of project, staff turnover on the project cost and schedule interim performance, and final outcome. This tool is used as an estimating tool as well as a real time forecasting tool for corrective action simulation. It also quantifies the impact of changes to the project as they are introduced.

The authors demonstrate the usefulness of the tool through a simulated project and used EV indices to demonstrate the effect of changes and re-work on the projects' performance. They conclude that changes introduced during the latter half of the project tend to have an increased impact on the project and generally lead to overruns.

The paper deals with controls at the project level and for planning purposes (simulating the project and tracking various indices at milestones throughout the simulation). The study is at a high level of control and does not demonstrate how this can be used on a more regular basis (e.g. monthly), or at more detailed levels of control. The authors also note the fact that system dynamics is only a part of a complete project controls system and suggest the use of a combination of mental models, traditional models, and system dynamic models for effective management.

In a recommended practice from AACE, the use of S-Curves is suggested for planning, monitoring, analyzing, forecasting, and control of project progress (The Association for the Advancement of Cost Engineering, 2010). S-curves are graphic displays of cumulative costs, labor hours, progress, or other quantities that are plotted against time. The S-Curve name comes from the shape of these graphs, which generally show a slower or flatter start, then a marked acceleration or steepening in the middle, and finally a tailing off again at the end. The author suggests that when progress or cost S-Curves are compared to the baseline plan, variances and trends emerge, thus allowing for better control of the project.

There is also a growing body of research on probabilistic project controls. This form of project controls utilizes simulation (e.g. Monte Carlo simulation) to develop distributions for S-curves, forecasts, and other indices in order to improve the usefulness of the traditional forms of project controls (Barraza, et. al., 2000).

Although there are many techniques and methods used in project controls, one method, EVM, has proven over many years to be reliable, relatively simple to use, and accurate enough to be one of the most widely accepted project controls methods in the construction industry (Project Management Institute, 2011).

2.2 Earned Value Management in Construction

“EVM is a management methodology for integrating scope schedule and resources; for objectively measuring project performance and progress; and for forecasting project outcomes” (P. 5, Project Management Institute, 2011).

It was first introduced in the project management environment in 1967 by the US Department of Defense through the Cost/Schedule Control Systems Criteria (C/SCSC) (Fleming & Koppelman, 2006), and subsequently expanded into the entire project management field. In 1996, the National Security Industrial Association (NISA) of America published a revised Earned Value Management System (EVMS), dropping the old terms from C/SCSC system and introducing the terms EV, AC, and PV (Lester, 2006).

The appeal of EVM is owed to its simplicity, ability to integrate time and cost performance measures, and ability to provide early warning signs on cost performance (overrun or under run) and schedule performance (ahead or behind) (Vanhoucke, 2009).

The Defense Contract Management Agency created a standard for EVM implementation on its project and states that EVM is a management tool used to integrate the technical breakdown of work with the cost and schedule (Defense Contract Management Agency - DoD, 2006). On construction work, the use of EVM is further broken into the following:

- Relates time-phased budgets to specific contract tasks or State of Work (SOW).
- Assigns authority and responsibility at work performance level.
- Objectively measures work progress.
- Accumulates and assigns AC.
- Properly relates cost, schedule, and technical accomplishments.
- Allows informed decision making and corrective action.
- Forecasts final outcomes.
- Supplies management at all levels with project information at their appropriate level of detail.

The following discussion on EVM is built off of the author's knowledge of the area, but is based on literary review of EVM standards and best practices. The key source for the EVM information is Project Management Institute (PMI) (2011); secondary sources include Fleming and Koppelman (2006), Vanhoucke (2009), and Lester (2006).

Similar to the discussion on the keys to a project controls system, EVM is built on three primary variables that are used to track project performance: Planned Value, EV, and AC. Before delving into the details of EVM, an understanding of these three variables is foundational.

- The Planned Value (PV) (or the Budgeted Cost of Work Scheduled (BCWS)) is the baseline value indicating expectations for project cost and schedule. The PV is essentially the planned monthly expenditures for each component of the project. These values are determined by distributing the baseline budget over the schedule. These values form the basis for performance monitoring throughout the project.

- Earned Value (EV) (or the Budgeted Cost of Work Performed (BCWP)) is the measure of actual progress made on the project in relation to the plan. This actual progress is based on a predefined method for measuring percent complete. It requires developing and adhering to a method for measuring percent complete based on physical progress, deliverables, or other means as required. The EV is a multiplication of the physical percent complete by the baseline budget. For example, if the work on a \$100 000 project is 10% complete, the EV would be 10% multiplied by \$100 000, to give \$10 000.
- Actual Costs (AC) (or the Actual Cost of Work Performed (ACWP)) is the measure of actual expenditures to date.

Although the most common form of measurement for EVM is monetary units, it can also use man-hours, or even units of time. The three variables presented above are used in EVM to calculate a number of performance indicators representing the present health of a project, as well as forecasting the expected at-completion cost and duration. These indicators include:

- Cost Variance (CV): a measure of the cost overrun/under run to date. It indicates the difference between the budget for work that has been completed on the project, and the actual expenditures to date.
- Cost Performance Index (CPI): the cost efficiency ratio, taken as the quotient of the budget for work completed (EV) over AC for work completed. An index of 1.0 indicates that costs so far are exactly the same as the budget for work done so far.

- Schedule Variance (SV): a measure of schedule deviation. It indicates the difference between the budget for work completed to date and the budgeted cost for work scheduled.
- Schedule Performance Index (SPI): the schedule efficiency ratio, taken as the quotient of the budget for work completed (EV) over the budget for work scheduled to date. An index of 1.0 indicates that activity is on schedule. Note that schedule performance is typically measured in units of dollars to allow for integration with cost performance.
- Estimate to Completion (ETC): forecasts the remaining costs to complete the activity/project based on cost and schedule performance to date.
- Estimate at Completion (EAC): combines the Forecast to Completion with the AC incurred so far to provide an updated estimate for the total expenditures that will be incurred by the end of the project.
- Variance at Completion (VAC): measures the difference between the originally planned budget and the updated Estimate at Completion.

Sample Project

The following provides a brief overview of how the EVM is applied to a project. The sample is derived from a sample project taken from Microsoft Corporation (2012) template for EVA. The three most important tasks for implementing EVM are:

1. Establish a baseline budget and schedule and convert this into the PV that will be used to measure progress and performance over the project life (shown in blue (marked with x) in Figure 1).

2. Define how progress is going to be measured. For example, a tunneling project typically measures progress based on advancement of the tunnel boring machine (meters of tunnel completed).
3. Track and record costs and progress.

If these three tasks are completed consistently and accurately, the above-mentioned performance indicators can easily be calculated and the following figures can be produced.

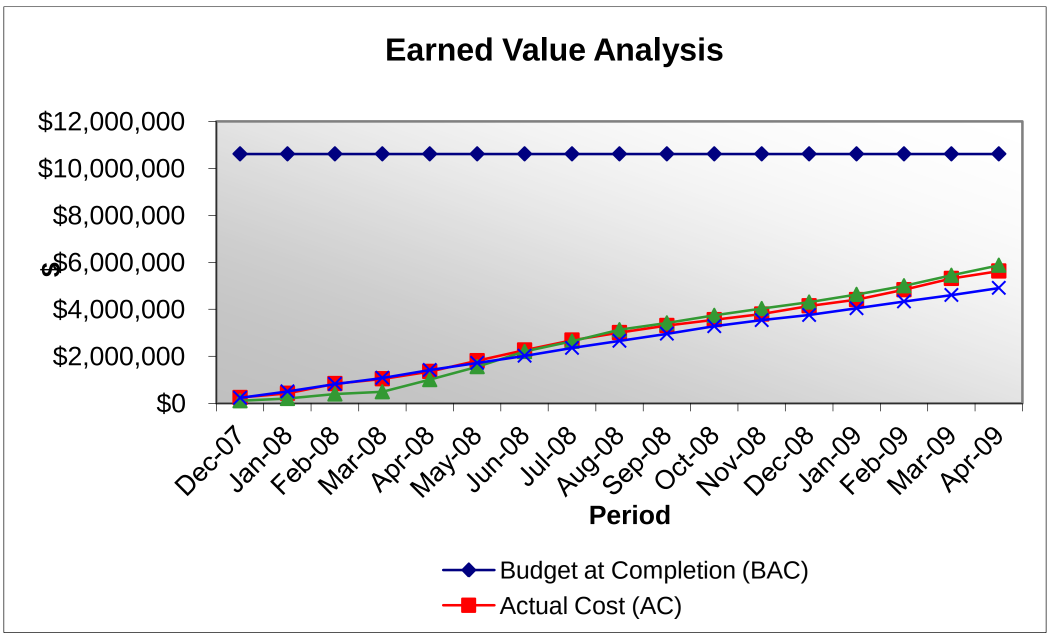

Figure 1 - Sample EVA (Microsoft Corporation (2012))

Figure 1 displays the typical EV figure. It indicates the PV for work on the project (Blue with "x"), the AC to date (Red with box), the EV or budgeted costs for work completed (Green with triangle), and the original budget that is expected to be spent by the end of the project. This figure shows that the project is ahead of schedule (Green is above Blue), and slightly under budget (Green is above Red), since approximately August 2008.

Figure 2 shows performance index tracking. The Red (with box) line represents schedule performance and the Blue (with diamond) cost performance. As can be seen, the project was struggling for the first six months with poor performance, but by June 2008 reached a more acceptable performance index of 1.0 (on budget and on schedule), and began to level out from there on. During the first six months, the feedback from these figures sparked the need for immediate corrective actions to be taken in order to remedy the deviations. EV provides a simple and immediate way of measuring the health of a project, indicating where corrective actions are required and how effective that action is.

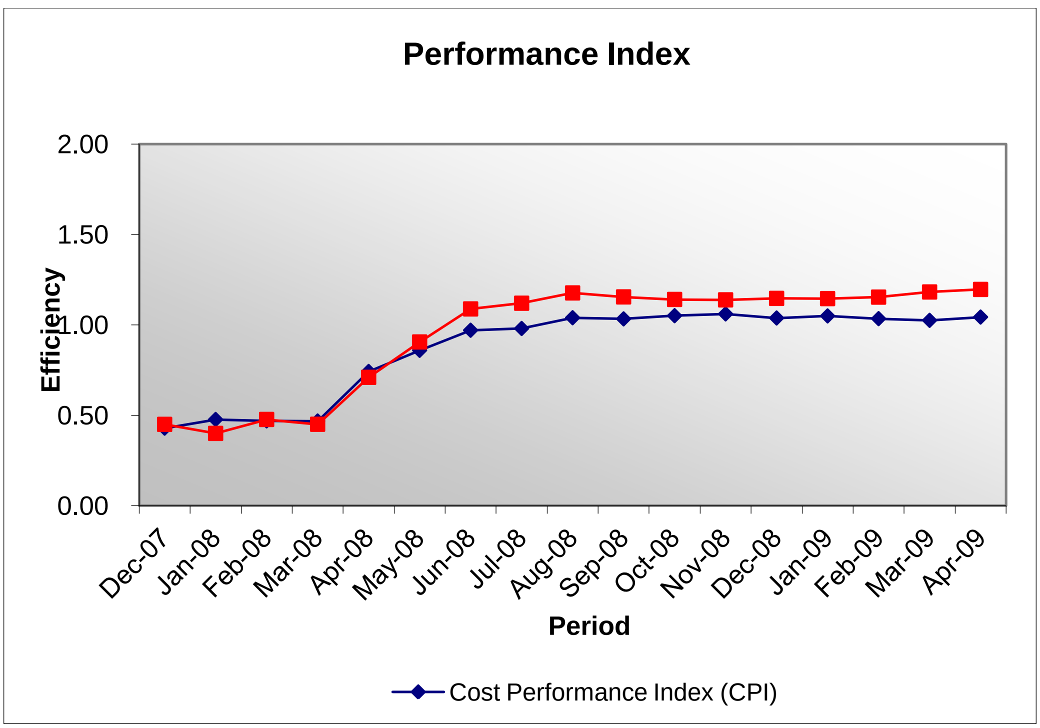

Figure 2 - Sample Performance Indices (Microsoft Corporation (2012)).

The next figure (Figure 3) presents the cost and schedule variances for the project and shows the expected variance at completion. Again, for the first six months the project was in poor shape with expected variance at completion totaling as much as $14,000,000. At this point, corrective action was implemented, and within a few months performance began to improve.

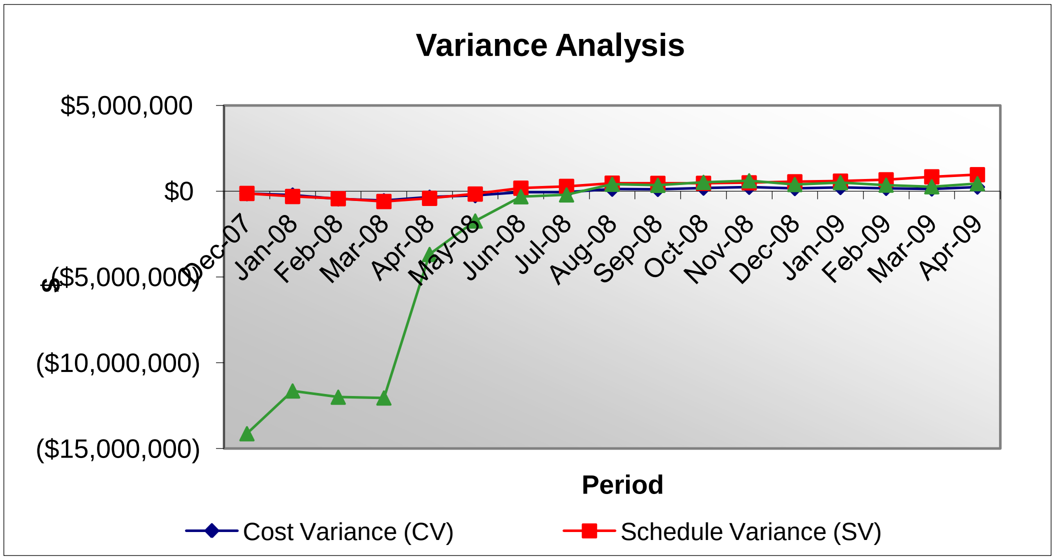

Figure 3 - Sample Variance Analysis (Microsoft Corporation (2012)).

The final figure (Figure 4) shows the most important number — estimate at completion. At a glance, the decision maker can see where the project is headed and can make an informed decision on where to go from here.

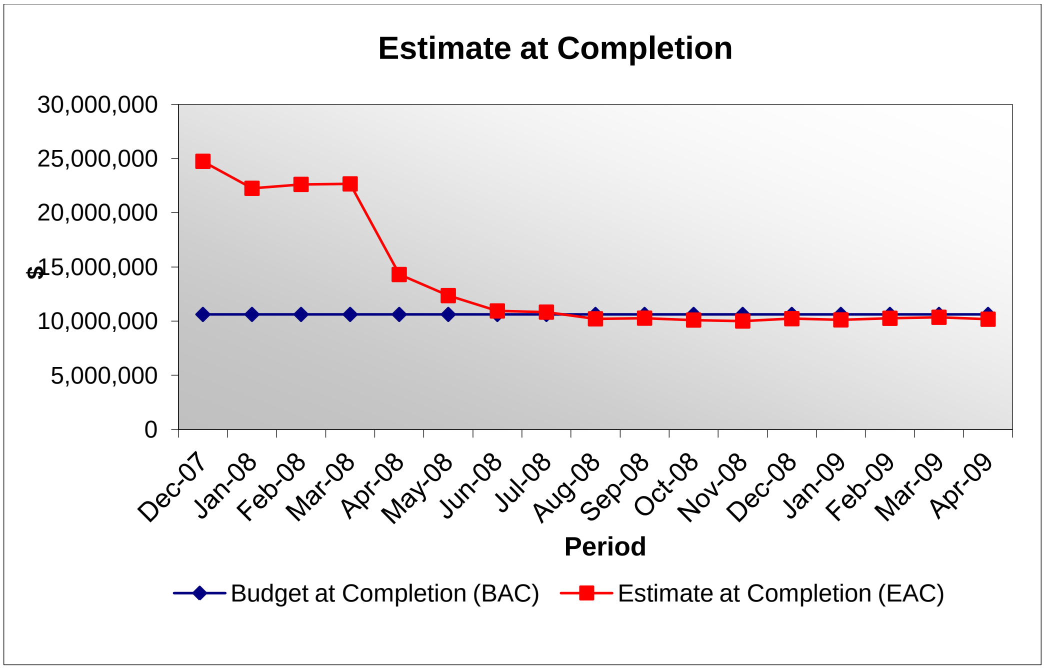

Figure 4 - Sample Estimate at Completion (Microsoft Corporation (2012)).

EVM is a widely used form of project controls in industry today. It offers a simple yet effective means of tracking project performance, and can be tailored to suit large, small, complex, or simple projects. Whether implemented at a project level or on individual tasks within a project, this method provides quick feedback on project health and indicates where corrective action is required. On an organizational level, EVM creates a structure for project management that can be used to standardize the way projects are tracked, and with its forecasting capacities, EVM becomes a very useful tool in planning future work in an organization.

The reader is referred to Practice Standard for Earned Value Management Second Edition from the Project Management Institute for more information on the traditional forms of EVM and its application (Project Management Institute, 2011).

2.3 Current Project Controls in Relation to Engineering Work

The EVM approach has been successfully applied to construction and the body of knowledge in this area is mature. The following literature demonstrates the more detailed requirements and techniques that have already been addressed in literature and can be related to controlling engineering work.

To start, previous literature has identified several keys to successfully implementing project controls on the engineering work:

- There should be constant and explicit monitoring of cost and schedule performance (Chang & Ibbs, Development of Consultant Performance Measures for Design Projects, 1998).
- The system should make use of interim milestone control in addition to project level control (Chang & Ibbs, Development of Consultant Performance Measures for Design Projects, 1998).
- To obtain project participant support, the system must train and allow for input and feedback from/to all participants in the system (Construction Industry Institute, 1986).
- For management commitment, the manager must be knowledgeable and supportive of the system (Construction Industry Institute, 1986).
- Implementation requires investment; at least 8% of the engineering budget goes toward project controls (including project management and overall team effort related to project controls and corrective actions) (Construction Industry Institute, 1986).
- The system must revise planned budgets and schedules when changes are introduced (Construction Industry Institute, 1986).

These points skim the surface of the requirements for implementing project controls such as EVM on engineering work. The next sub-sections will discuss literature in the area of: Baseline Development; Baseline Maintenance; Progress and Earned Value; Performance, Forecasting and Corrective Action; and Reporting and Decisions Making.

2.3.1 Baseline Development

2.3.1.1 Work Breakdown Structure

“The work breakdown structure (WBS) is a deliverable oriented hierarchical decomposition of the work to be executed by the project team to accomplish the project objectives. It organizes and defines the total scope of the project. Each descending level of detail represents an increasingly thorough definition of the project work” (P. 17, Project Management Institute, 2011).

WBS is the back-bone of any project controls system in engineering and construction. Developing a WBS is a process of breaking down a project into smaller and smaller chunks of work until they are of adequate size to be properly managed and controlled. This exercise is first used on a project to layout the scope of work, dividing the project into phases, types of work, geographic areas, work sequences, and activities. The WBS groups and categorizes the scope in order to organize the work as much as possible. Lester (2006) suggests that in this way the WBS is the logical starting point for all subsequent planning structures on a project. The WBS is not just the work breakdown structure, but also is the starting point for the schedule precedence diagram, feeds into the Cost Breakdown Structure (CBS), Organization Breakdown Structure (OBS), Risk Breakdown Structure (RBS), and forms the back-bone of the communications processes. That being said, the primary purpose of the WBS is to control the project by setting a framework to allocate resources (human, material, and financial) and giving time constraints to each task (Lester, 2006). The WBS becomes the center point for communicating project information. It balances the level of detail needed for proper control with the necessity for manageable work-loads and efficient project processes (Project Management Institute, 2011)

Once a project is broken into smaller, more manageable tasks, control systems can be established and task owners can be assigned to these tasks. The owners of assigned tasks can prepare in detail the required resources and time constraints that will then feed into the baseline that each task will be controlled against (Project Management Institute, 2011).

Because of the value and necessity of the WBS in design and construction, the Department of Defense (DoD) in the United States prepared a WBS Handbook to standardize its use across DoD projects. The document explains that the goal of the WBS is to develop a structure that defines logical relationships between project components, but does not constrain the contractor's/engineer's ability to define or manage resources. A key short-coming of the WBS is that it is often difficult to integrate the owner's WBS used to plan the work with the contractors WBS used to execute the work. This can create challenges in controlling work, integrating organizational structures between owner/engineer and contractor, and capturing knowledge related to costs and durations for particular tasks to be used in the planning of future work. The DoD acknowledged this issue by suggesting a WBS framework that could be adopted and subsequent levels of the WBS filled out in more detail by the contractor. In this way, the WBS developed during planning and design would specify the higher level work-packages on the WBS where control structures would be integrated, and give the contractor the freedom to plan the details of their work, such as schedule and responsibility, to the desired level.

The DoD handbook goes on to explain that the WBS serves as a coordinating medium for:

- progress,
- performance,
- cost,
- schedule,
- technical data,
- summaries to upper management levels, and
- projected, actual, and current states of individual items/elements.

When the WBS is structured well and combined with cost estimating, integrated scheduling, EVM, and risk management, it allows project status to be continually visible to project management, and allows project management to identify, coordinate, and implement changes necessary to keep the project on track. It also facilitates the tracking of data between projects for useful performance comparisons.

One of the key components of the WBS is its use as an EVM structure. It provides the framework for EVM baseline, calculation, and reporting. The ANSI EVM standard requires the establishment of control accounts (GEIA, 2007). These control accounts correspond to the level on the WBS where cost and schedule are integrated, physical progress is measured, and EVM is applied

(United States of America Department of Defense (DoD), 1998). It is a "management control point where scope, budget, AC, and schedule are integrated and compared to earned value" (P. 8, Project Management Institute, 2011).

Defining the level of detail for the WBS and setting control accounts are important in the successful implementation of EVM. Control accounts that are too detailed will easily become overwhelming to manage due to the sheer number of accounts to control. Control accounts that are too coarse can prevent proper controls and make it difficult to pinpoint the areas of poor performance (Project Management Institute, 2011).

Determining which work-packages on the WBS are control accounts is an exercise in itself. Defense Contract Management Agency – DoD (2006) applies a cost benefit analysis to determine which work-packages will be control accounts. This involves a process of schedule risk assessment using Monte Carlo simulation. This determines the level of schedule criticality of each work-package based on its impact to the project, and milestone completion dates.

Vanhoucke (2009) states that the ease of implementation of a project controls system is crucial to its success. Crucial to this is the level of project tracking detail and the resulting level of management effort required to investigate and correct poor performance. There must be a balance between the level of detail and the ease of project tracking. The author argues that, despite opposition, project controls, and particularly schedule control, are best suited to be tracked by EVM at the higher WBS levels (cost accounts or higher) and performance indicators are to be used to determine when to drill down into the details. This allows the efficient balance between time spent performing the analysis, and effectiveness of the controls.

One of the key short-comings in WBS development on projects is lack of full integration of the schedule and cost breakdown structures. Hendrickson, (2008) emphasized the complex inter-relationship between cost and schedule that is inherent in actual projects. The author states that while this relationship is implicitly recognized by project managers, it is much less common to find an effective project controls system which includes both cost and schedule. Cost systems are often defined by the organization and are often not suited to be used in scheduling. Schedules are generally customized to the project at hand and project managers avoid constraining the schedule breakdown to the cost accounts. This leads to project managers performing the tedious task of relating the two sets during each period of the project, if an EV type of control system is being used.

Hendrickson (2008) recommends the use of a work element matrix where all detailed cost accounts are linked to project activities. The problem with this approach, as sited by the author, is the enormous amount of data collection, storage, and book-keeping required to maintain such a matrix on a construction project. This problem has left this technique generally un-used for integrating cost and schedule.

2.3.1.2 Creating the Planned Values

As stated above, projects are typically planned and controlled using a schedule and budget. These are generally broken down into the packages of work to be performed. In EVM, it is prerequisite that the cost and schedule are linked in order to develop the baseline for performance monitoring. The primary exercise in establishing the EVM baseline is to distribute the cost of work-package or activity over its schedule. This necessitates a close relationship between the cost breakdown and the schedule breakdown structures. In fact, the ideal situation is that these breakdowns are one in the same.

Project Management Institute (2011) suggests that the schedule structure should be based on the logic of the WBS. It is suggested that the structure include a minimum of four levels:

- higher levels of the WBS,
- control accounts,
- work-packages or planning packages, and
- activities.

The cost structure should also be based on the WBS and the cost and schedule should come together at least at the work-package level.

Once the cost and schedule are identified for a given work-package, the costs needs to be distributed over the schedule in a manner representative of the actual work effort over time. The baseline should model, as accurately as possible, how the work is expected to progress. For example, if an activity is planned using a uniform distribution of budget over the scheduled duration, but in reality the work-flow will start off fairly slow and pick-up considerably toward the end, then the EVM results will be skewed and show incorrect results until the activity is done.

The approach offered in standards to accomplish this budget distribution is to integrate the cost and schedule to as detailed a level as practicable and use uniform distribution. This approach works well if two criteria are met: (1), that the WBS can be broken into enough detail that the activities on the lowest level of the WBS have a relatively small duration (generally no more than a month); (2), the cost and schedule can be integrated at this level. This is often not the case for engineering work, as will be discussed in this chapter.

Chao and Chien (2009) offered a technique to facilitate this distribution. They proposed a method for determining S-curves for a project through the use of a neural network and polynomial function. This technique was used at the project level to allow for early development of S-curves during the pre-planning stages of a project. The technique used 90 projects to train the neural network. Although they only applied this at the project level, this approach could be utilized at more detailed levels of the WBS.

In their work, they also touch on the distribution of cost over schedule by stating that linking cost to schedule has generally always been uniform. The cost is distributed uniformly over the task. This works when the level of detail is sufficient enough that it is at the activity level of a project schedule. In design projects, the activity level is much less defined and the WBS is generally at a higher task or even discipline level.

2.3.2 Baseline Maintenance

There are a variety of change types and each has its own impact on the baseline of a project. But, regardless of type or impact, the EVM baseline must be continually maintained in order to keep the performance results accurate and useful.

Project Management Institute (2011) developed an EVM implementation guide that contains a full chapter dedicated to baseline maintenance. It suggests that the primary source of a change on a project is due to newly added (or removed) scope. In this case it is recommended that you supplement the existing baseline with the addition of a new control account or work-package below an existing control account. If a change to an existing control account or work-package is required, it is suggested to close this control account and create a new, revised account. The closed account should have its budget set to the EV, and the AC to date remains in the account. This technique eliminates the schedule variance, but allows any cost variance to remain as a historic record and contribution to the total project variance.

In most standards, it is often stated that retroactive changes must also be controlled. That is to say that changes to the baseline that impact what has been reported in the past need to be accounted for. Some standards prohibit the use of changing what has already been reported, yet this will tend to decrease the accuracy of the EVM system, if these changes are significant. Despite the emphasis on accounting for retroactive changes, literature offers few practical techniques to actually do this.

Project Management Institute (2011) also delineates between the changes discussed above and wholesale schedule or budget changes. It terms these types of changes “re-baselining” or “re-programming.” This involves larger or even wholesale change to the EVM baseline due to complete re-vamping of the schedule, scope structure, or budget. Re-baselining is done when cost or schedule targets become unrealistic or there are major changes required to the scope structure.

The Defense Contract Management Agency – DoD (2006) recommends that a major re-baselining should occur when:

- the original baseline becomes unrealistic,
- re-organization of work or resources is necessary,
- the decision is made to use a different engineering or manufacturing approach, and
- existing budgets need to be re-phased to different work-packages or schedules.

The literature reviewed offers little in terms of practical techniques to actually implement change management.

2.3.3 Progress and Earned Value

In engineering work, the same techniques used to measure progress in construction need to be adapted to the conditions of engineering work to be useful. Most of the same techniques can be used, but there are some more suitable to engineering type work than others.

Eldin (1991) demonstrated that in the past, a typical form of progress measurement and tracking for design work was the use of a drawing control log (DCL). DCL is a listing of project drawings by number and title, man-hours (MH) budgeted and MH used, forecast of MH complete, percent complete, planned start and finish dates, and actual start and finish dates for each drawing. The shortfall with this approach is that MH forecasts and percent complete are subjectively input and criticality or weight of different deliverables is not accounted for. As such, it is only a reporting tool and does not generate information. The conclusion drawn by Eldin (1991) is that the DCL as a controls tool is not enough.

To make progress measurement and control more effective, research started to look into the actual deliverables of engineering work.

2.3.3.1 Deliverables

A primary factor in measuring design phase work is to identify the deliverables. A primary difficulty with transferring construction type project controls into design is that with engineering work there are far fewer deliverables than in construction (Eldin, 1991).

A study by the Construction Industry Institute (1986) took an in-depth look at project controls for design/engineering work and concluded that the products or deliverables of engineering work are:

- documents to guide procurement, construction and manufacturing,
- studies ,
- procedures and operating manuals, and
- various consulting services.

Eldin (1991) came to a similar conclusion, stating that the primary deliverables of the design phase are:

- drawings,
- specifications,
- project books (manuals, procedures, etc.), and
- material documents (material take-off sheets, data sheets, purchase orders, etc.).

These deliverable are the natural starting point in developing progress measurement techniques for engineering work. It is feasible for most designers to estimate accurate numbers of engineering documents and work-hours required to complete engineering tasks (Construction Industry Institute, 1986); however, Eldin (1988) states that the details of the progress measurement system should be set-out before work starts. So the question becomes: is it feasible to determine all drawings, specifications, manuals, and services that will be required for the engineering work before the work starts?

Construction Industry Institute (1986) discussed measuring progress using less than the complete list of deliverables; for example, only tracking progress using drawings. A survey of engineering companies showed that 66% of firms in the study used 55% of total work to measure progress and ignored the other effort. In most cases, drawings are typically used for progress updating. There was no indication that this yielded ineffective project controls results, but it was suggested, rather intuitively, that the more deliverables used to measure progress the better.

To support early identification of deliverables, Eldin (1991) suggests identifying the parent documents that will require the upfront effort and the child level documents can build off the parent as the scope is better defined.

Take the typical breakdown of engineering effort provided by Construction Industry Institute (1986) below:

- 40% for drawings,
- 15% specification development,
- 10% design support activities,

- 25% procurement activities, and
- 10% other activities.

This shows that the clearly definable deliverables (drawings, specifications) amount to 55% of the total engineering effort. This proportion is reiterated by Eldin (1991) where it is stated that project drawings require about 50% to 60% of engineering effort and indirect engineering costs project management, supervision, support services range from 18% to 35% of direct cost. Is it enough to track progress based on 50% to 60% of the engineering effort?

Typically, contract progress is tracked against work activities with definable deliverables to the client; however, costs are tracked against all activities (recoverables, dispursements, travels, etc.). An effective project controls system must control both work and cost, but this does not mean that progress measurement should include indirect or supporting work. Inclusion of indirect work will distort progress on deliverables (Construction Industry Institute, 1986).

On the other hand, Eldin (1991) states that control budgets include supporting work (engineering analysis, quality control, project management, and related services) and therefore controls system must include these.

In the opinion of the author, it is worthwhile to track progress for support and management related to these amounts to a significant portion of effort for engineering work, especially on larger design projects (roughly greater than $5 million). The techniques used to measure this progress need to be reflective of how costs will be incurred for this work, and must be relatively simple to implement in order to add the most value.

The following section discusses the current progress measurement techniques identified in literature.

2.3.3.2 Measuring Percent Complete

As mentioned previously, EVM is built on the premise that progress is measured based on physical progress of an activity/deliverables. Value for work is earned through physical completion of the task/deliverable in question through the formula: EV = (Budget) x (Physical Percent Complete).

In the EVM standards reviewed, progress is measured based on several standard techniques divided by the type of work.

GEIA (2007) and Project Management Institute (2011) divide progress into 3 types: discrete effort, apportioned effort, and level of effort.

- Discrete effort: these are efforts with definable scope and objectives that can be scheduled and progress can be measured.
- Apportioned effort: these tasks involve work for which planning and progress are tied to other efforts.
- Level of effort: this involves work scope of a general or supporting nature for which performance cannot be readily measured.

For discrete effort, progress is measured using three primary techniques: valued milestone, physical measure, standard hours, and management assessment.

Valued milestone involves assigned value or weight to individual schedule milestones of a task, and progress is earned as these milestones are completed. This includes simplified, fixed-formula versions as well as highly specific physical measurement. The fixed formula approach is where percentages are assigned for the start and end of a work-package (e.g. 50/50 method where 50% of progress is earned when a package has started and 50% is earned when it is compete). This method is best used for activities that have a duration of no more than two reporting periods.

The physical measurement approach involves measuring progress based on completion of representative units (e.g. meters of pipe complete). This is a more explicit approach and is generally preferred over the others, but may not be realistic for some types of work.

For standard hours, the budget (man-hours or other units) is time-phased in relation to the standard hour plan set in advance from experience with a similar task. Progress is accrued in proportion to the standard hours.

For management assessment, progress is measured based on a subjective management assessment of the work whereby a percent complete is assigned to the task based on experience of the manager overseeing the work.

The apportioned effort types of work require a different form of progress measurement than state above. For these tasks, the progress status at any point in time is measured based on the status of the base accounts to which this work is tied.

Level of effort types of work measure progress according to the time-phased effort plan for the work. In this way, progress is earned through the passage of time according to the effort that was planned for each period.

These techniques for measuring progress are standard in construction although many derivatives of such techniques exist.

The Construction Industry Institute (1986) suggested a list of progress measurement techniques that would be suitable for design phase/engineering work. These are Units Complete, Incremental Milestones, Start/Finish Percentages, and Ratio or Judgment. **Table 1** provided below describes these techniques and provides examples of their use.

Table 1 – Progress measurement techniques proposed by CII.

Technique	**Suitable When?**	**How?**	**Example**
Units Complete	Total scope consists of number of equal (or nearly equal) parts with relatively short duration to complete each unit (hours, days).	Divide units completed by total units to complete.	Writing a number of specifications of a given type.
Incremental Milestones	Activities with significant duration and composed of recognizable, sequential sub-activities.	Define milestones and weights and award progress as the activity accomplishes each milestone.	Control of drawings based on milestones for each.
Start/Finish Percentages	Activities which lack readily definable milestones and or effort or time required is difficult to estimate (planning, designing, manual writing, studies, etc.).	Assigning progress credit (20 to 50%) when activity starts and 100% when activity finishes.	Special study start 20%, special study finish 100%.
Ratio or Judgment	Activities that span a long period of time and involve no definable end product and are estimated or budgeted on a bulk allocation basis rather than production.	Based on actual hours spent compared to budgeted hours.	Project Management spent 70 of 100 hours. Percent complete is 70%.

The Construction Industry Institute (1896) study also offered example drawing and procurement milestone lists to be used to measure progress for each individual deliverable. The percentages shown next to each milestone indicate where the progress should be at when that milestone is complete. A key to developing these milestones is that they need to meaningful points in completion of the task. The other key component is that the weight given to each milestone needs to be reflective of the typical amount of effort required to reach each milestone.

Drawing:

- Start drafting 0%.
- Drawn, not checked 20%.
- Complete for office check 35%.
- To owner for approval 70%.
- First issue 95%.
- Final issue 100%.

Procurement:

- Bidder list developed 5%.
- Inquiry document complete 10%.
- Bids analyzed 20%.
- Contract awarded 25%.
- Vendor drawings submitted 45%.
- Vendor drawings approved 50%.
- Equipment shipped 90%.
- Equipment received 100%.

This document also offered a proposed progress measurement technique which measured progress based on quantities designed. That is to say, tracking of engineering production based on quantities (cubic meters of concrete, meters of pipe, etc.) in order to parallel engineering control with construction control. A major hurdle is developing the budgeted quantities at the start of the engineering work. This is a significant hurdle and is not considered a feasible approach at this stage for engineering work.

Eldin, (1991), recognizing that a quantitative approach was needed to accurately measure progress in the design phase, took a similar approach to measuring drawing progress based on incremental milestones. In this research, different rules of credit need to be created for each document type in engineering work. An important note is that partial credit between milestones may also be allowed if appropriate in order to not place artificial constraints on progress measurement that could skew progress inaccurately. This means that assigned weight for each milestone is the ceiling for each milestone but does not limit in between progress (partial progress).

Engineering Document Milestones:

- Drawing started (title block complete) (5%).
- Issued for engineering review (45%).
- Checked and signed by engineer (20%).
- Checked and signed by project manager (5%).
- Client comments incorporated (20%).
- Issued for bid/construction (5%).

Using this milestone approach, progress for a deliverable is calculated using the formula note that the term milestone is replaced with control point in Eldin (1991) formulae:

$$Percent\ Complete\ = \sum (CPi) * (Ai) \qquad \text{Equation 1}$$

Where:

CPi = the earning percentage associated with control point number i

Ai = the actual progress accomplished on control point number i

Once progress is measured at the lowest level of a progress measurement system, there is often the requirement to roll this progress up to the higher levels on the WBS for summary purposes.

2.3.3.3 Progress Rolled-up

The primary technique used to roll-up progress in practice in construction is called the Weighted Percent Complete method. This technique involves computing weight of each work-package at a level of the WBS, multiplying the progress of each by its weight, and then finding the sum of the weighted percent complete for each subsequent level of the WBS. It is noted that this is a cumbersome approach to rolling up progress and does not allow for changes to be made easily. If a change of budget is made to one work-package, all weights for all work-packages at that level and at all higher levels of the WBS have to be recalculated (Eldin, 1988).

Lester (2006) points out that one of the main differences between traditional progress tracking and EVA is that the roll-up of progress is based on EV and no longer requires weights. This saves the laborious processes of creating weights at the beginning of the project and redistributing weights when changes are made. In this way, the roll-up of progress from one level of the WBS to the next would be based on adding the EV to date and dividing the total budget for that item. It does not require the changing of existing weights. To provide an example of this, take the project that requires three tasks A, B, and C, below in **Table 2**.

Table 2 – Sample project for progress roll-up example.

Task	**Budget Hours (1)**	**Task Weight (2)**	**Progress (3)**	**Weighted Progress**
A	1000	33%	50%	17%
B	1500	50%	10%	5%
C	500	17%	20%	3%
Total	**3000**	**100%**		**25%**

The traditional form of progress reporting would calculate the weighting that each task contributes to progress by dividing the task budgets by the total budget. As can be seen, each task has progressed a certain amount. The rolled-up progress to the project level requires the multiplication of task weight by progress. This weighted progress is then summed to give the total project progress. In this example, the total progress is 25%.

Now often in design and construction projects, there are changes to the existing scope and tasks are added to the project. Using the same example as above, suppose we add a Task D with a budget of 1200 dollars and no progress (refer to **Table 3)**. In the traditional form for progress calculations, this change would require a wholesale re-distribution of task weights as can be seen in column (2). This recalculation has a ripple effect on the weighted progress calculation which now shows decreased "weighted progress" for each task. The total rolled-up progress for the project is now 18% instead of the 25% from the example in Table 2.

Table 3 – Addition of new work-package to example

Task	**Budget Hours (1)**	**Weight (2)**	**Progress (3)**	**Weighted Progress**
A	1000	24%	50%	12%
B	1500	36%	10%	4%
C	500	12%	20%	2%
D	1200	29%	0%	0%
Total	**4200**	**100%**		**18%**

Now, using the same example as above and using the EVA approach suggested by (Lester, 2006), the concept of value hours is applied in column (3). The value hours are calculated by multiplying the task budget and the progress. The rolled up progress is then determine by summing the value hours for the tasks and dividing by the total budget.

Total Progress = 750 Value Hours / 3000 Total Hours = 25% Complete

Table 4 – Sample project using EVA approach.

Task	**Budget Hours (1)**	**Progress (2)**	**Value Hours / Earned Hours (3)**
A	1000	50%	500
B	1500	10%	150
C	500	20%	100
Total	**3000**	**25%**	**750**

If a new task is added to the project, the progress measurement system requires only re-calculating the total budget and from there the same Total Progress calculation can be used as above to give the updated progress.

Total Progress = 750 Value Hours / 4200 Total Hours = 18% Complete

Table 5 –Sample project adding new work-package.

Task	Budget Hours (1)	Progress (3)	Value Hours / Earned Hours
A	1000	50%	500
B	1500	10%	150
C	500	20%	100
D	1200	0%	0
Total	**4200**	**18%**	**750**

This example demonstrates that the EV concept reduces the amount of effort to roll-up progress to the various levels of the WBS, and also is better equipped to handle changes to the scope during the project.

The Construction Industry Institute (1986) suggests a similar approach to progress roll-up for design work using a sum of all EV from the sub-tasks for a particular account and dividing by the total budget for that account (sum of all sub-task budgets). An example would be percent complete for a Roadwork account being the sum of earned progress for all individual roadwork-packages 105 Street, 106 Street and 107 Street, divided by the total budget for this work.

Congruently, in Eldin (1988) and Eldin (1991) the progress roll-up is the sum of EV divided by sum of budgets at each level.

2.3.3.4 Earned Value Units

A key decision to make when implementing EVM on any project is the units that will be used for the EV calculations. EVA standards indicate typical units to be work-hours or currency and do not specify a desired unit. Eldin (1991) states EV can be in terms of man-hours, dollars, or any other work units desired. However, Construction Industry Institute (1986) states control based on work-hours for individual activities is the best form of control. Lester (2006) proposes the use of site man-hours and cost (SMAC) developed by Foster Wheeler in 1978 for various types of work including design work. This approach is a man-hours based EVA where by budgets and progress are all tracked in terms of man-hours (Lester, 2006).

2.3.4 Actual Costs

Project Management Institute (2011) states that is it important for AC to be recorded in the same period that EV is recorded for that work. If these two are off sequence there is potential to significantly distort EVM results.

A noted issue that may occur on projects is a delay in determining AC. This can be due to a variety of reasons including time delay in reporting this information, or accruing of indirect costs. In this situation, a few techniques are briefly mentioned: trend analysis, correlation, and parametric models; however, none are discussed in any detail in the document.

Construction Industry Institute (1986), which specifically looked at application of EVM to design work cited a similar issue involving the time lag between cost obligation and receipt of invoices making it difficult to keep the system up to date and accurate. No solution was offered.

There is considerable literature available for cost accounting, but that is beyond the scope of this research. The main purpose of this chapter is to discuss the unique issues with tracking AC for EVM on engineering work.

2.3.5 Performance, Forecasting, and Corrective Action

Literature in the area of EVA is extensive. The following provides a summary of literature related to EVA and specifically the research that is relevant to controlling engineering work.

"One of the primary tasks of a project manager is making decisions about the future" (P. 9 (Vanhoucke, 2009). To support this role, proper forecasting techniques are required. Forecasting in EVM has long been a topic of research and there are many different variations on forecasting techniques and formulae.

The traditional forms of EVM performance calculations form the basis of the proposed approach; however, they are augmented and refined by research that has been completed in the area and is relevant to controlling engineering work. The following section describes the more advanced EVM techniques for calculating performance (particularly for schedule performance) and forecasting applicable to engineering work.

The forecasting techniques discussed in this literature review were focused on EVM-based techniques in order to be aligned to the project controls system that is being discussed in this document. The majority of these forecasting methods use trending and index based techniques (Nasser, 2005). These techniques have been considered due to their alignment to the EVM project controls system that is the topic of this research as well as the simplicity with which these techniques can be implemented. A primary focus of this research is to develop a project controls approach that can readily be put into practice. This necessitates a relatively intuitive and simple approach to forecasting.

Project Management Institute (2011) offers a list of well-established EVM forecasting techniques. On the one hand, it is suggested that the formal estimate at completion (EAC) be based on a detailed review of remaining work and cost for that work; on the other hand it puts forward a list of the established forecasting formula that can be used in various situations to augment or verify the formal EAC.

The formal EAC or management forecasted cost is based on a bottom-up estimate of the cost of remaining work on the project, and this technique has no replacement when it comes to accuracy and reliability in terms of forecasting techniques. The forecasting techniques used in EVM are statistical techniques that take past performance, in one form or another, and project this into the future to calculate an estimate of the final cost or duration of the project. These techniques can be a good indicator on the effect of current performance on the end result of the project. They should not, however, be relied on as a formal estimate at completion (Project Management Institute, 2011).

Five scenarios are offered in the standard to determine which forecasting approach is best used for forecasting final cost of the project:

- Future cost will be completed at the budgeted rate.

$$EAC = AC + (BAC - EV) \qquad \text{Equation 2}$$

- Future cost performance will be the same as cumulative past performance.

$$EAC = AC + \frac{(BAC - EV)}{CPI} = \frac{BAC}{CPI} \qquad \text{Equation 3}$$

- Future cost performance will be the same as the performance over the last three periods.

$$EAC = AC + \frac{(BAC - EV)}{CPI_{last\ 3\ period\ average}} \qquad \text{Equation 4}$$

- Future cost performance will be influenced by both past cost and schedule performance.

$$EAC = AC + \frac{(BAC - EV)}{CPI \times SPI} \qquad \text{Equation 5}$$

- Future cost performance will be influence by a combination for past cost and schedule performance using some proportion of the two.

$$EAC = AC + \frac{(BAC - EV)}{w_{CPI}CPI \times w_{SPI}SPI} \qquad \text{Equation 6}$$

This book suggests the use of multiple forecasting equations simultaneously to provide a range of possible forecasts from which to rationalize the management forecast at completion.

Nasser (2005) conducted a detailed review of forecasting techniques and the following is a summary of the EVM techniques that were discussed.

Christensen (1993) conducted a review of a large number of forecasting techniques. They generated a generic forecasting equation:

$$EAC = AC + \frac{(BAC - EV)}{index} \qquad \text{Equation 7}$$

Where:

Index = the performance index used to forecast future performance.

The index in this equation can take on one of four values: CPI, SPI, CPI*SPI, or (w_1*CPI +w_2*SPI).

A comparative study conducted over 16 years attempted to draw conclusions on which formulas were superior. This study found that no one formula or model is always superior. It did not conclude superiority between regression models or index-based models. It did determine that the accuracy of index-based forecasting is dependent on the stage and phase of the project. In particular, it suggested that averaging the performance indices over shorter periods (e.g., 3 months) is often more suitable for forecasting during the mid-stages of a project (roughly 25% to 75% project completion) when the majority of the work is taking place.

Fleming and Koppelman (1994) proposed the use of the combined cost and schedule index for forecasting future performance. That is to say the formula for forecasting suggested is:

$$\mathrm{EAC} = \frac{\mathrm{BAC}}{\mathrm{CPI} \times \mathrm{SPI}} \qquad \text{Equation 8}$$

In the same research, they propose that the forecasting for schedule performance can be accomplished through the equation:

$$\mathrm{D} = \frac{D_b}{\mathrm{CPI} \times \mathrm{SPI}} \qquad \text{Equation 9}$$

Where: D = forecasted duration at completion

D_b = planned project duration

Shtub et al. (1994) used the constant performance for CPI and SPI which is built on the assumption that future performance will not change from the past cumulative performance.

$$\mathrm{EAC} = \frac{\mathrm{BAC}}{\mathrm{CPI}} \qquad \text{Equation 10}$$

$$D = \frac{D_b}{SPI} \qquad \text{Equation 11}$$

Alshaibani (1999) introduced the additional forecasting performance index that accounts for future improvements in the equation. The approach uses the same forecasting formula proposed by Christensen (1992), and modifies the forecasting index using the following equation:

$$Forecasting\ index\ = (\propto \% + CPI) \qquad \text{Equation 12}$$

$$\boldsymbol{or}$$

$$Forecasting\ index = (\propto \% + CPI)(\propto \% + SPI) \qquad \text{Equation 13}$$

Where:

$\propto \%$ is between 0 and 100 and is used to show the improvement to CPI or SPI that is expected.

Nasser (2005) summarized a plethora of methods for calculating the forecasted cost at completion that are scattered throughout EV literature.

Although there are many other techniques for forecasting including probabilistic methods, fuzzy logic models, judgment-based models, or more advanced Markov Chains or Baysian Inference, etc., this research focuses on those models that are derivatives of the EVM approach, as these are widely accepted and can be used with relative ease and simplicity. These attributes significantly add to the likelihood of them being used in practice which is a primary objective of this research.

2.3.5.1 EVM Schedule Performance and Forecasting

EVM has often been criticized over the years for its inability to accurately monitor schedule performance. The problem lies in the fact that in traditional EVM the unit of measure is the currency or man-hours. Although this allows the integration of cost and schedule performance, it cannot provide a forecast of the duration at completion, and tends to inaccurately portray schedule performance, especially towards the end of the project. For example, given a project that is originally supposed to take 10 months in duration and was actually completed in 11 months, the traditional form of EVM would provide an SPI of 1.0 and an SV of 0 ($ or man-hours) at completion even though the schedule was overrun by one month (Vanhoucke, 2009; Project Management Institute, 2011).

For this reason, researchers in the early 2000's developed various EV techniques to fill this void in measuring and forecasting schedule performance.

Vanhoucke (2009) discusses three predominant schedule performance and forecasting techniques that have been introduced in academia.

Anabari (2003) introduced a method that utilizes two new metrics, the Schedule at Completion (SAC) and Time Variance (TV). The SAC is the planned duration of the project and is the time equivalent of the Budget at Completion (BAC). The TV is the variance between earned time and elapsed time and provides the same information as SV. In order to calculate TV, the author introduces an additional value called Planned Value Rate (PV_{rate}) which is the average budget expenditure per period of the project. TV is calculated by dividing the traditional SV in units of dollars by $PV_{rate.}$ The formulae are provided below:

$$PVrate = \frac{BAC}{SAC}$$ Equation 14

$$TV = SV \times PVrate$$ Equation 15

The purpose of TV is to provide insight into what the duration of the project will end up being at completion.

In this technique, three forms of forecasting are proposed as:

- Remaining work will go according to original plan.

$$Forecasted\ Duration\ at\ Completion = SAC - TV$$ Equation 16

- Future work will follow to current schedule performance trend.

$$Forecasted\ Duration\ at\ Completion = \frac{SAC}{SPI}$$ Equation 17

- Future work will follow the Schedule-Cost performance trend (SCI) (cost and schedule both have an impact on the final duration and are inseparable).

$$Forecasted\ Duration\ at\ Completion = \frac{SAC}{SCI}$$ Equation 18

Vanhoucke (2009) discusses Jacob's (2003) proposed Earned Duration (ED) method which uses earned duration as the ratio of Actual Duration to the current SPI.

$$ED = \frac{AD}{SPI}$$ Equation 19

In this technique, three forms of forecasting are proposed:

- Remaining work will go according to original plan.

$$Forecasted\ Duration\ at\ Completion = AD + (PD - EV) \qquad \text{Equation 20}$$

- Future work will follow to current schedule performance trend.

$$Forecasted\ Duration\ at\ Completion = \frac{PD}{SPI} \qquad \text{Equation 21}$$

- Future work will follow the Schedule-Cost performance trend (SCI) (cost and schedule both have an impact on the final duration and are inseparable).

$$Forecasted\ Duration\ at\ Completion = AD + \frac{PD - ED}{SCI} \qquad \text{Equation 22}$$

This approach also offers the metric "To-complete Schedule Performance Index (TCSPI)" to be used to determine the additional effort needed to complete the project within the planned duration, or the latest revised schedule duration (LRS).

$$TCSPI = \frac{PD - ED}{PD - AD} \qquad \text{Equation 23}$$

$$TCSPI = \frac{PD - ED}{LRS - AD} \qquad \text{Equation 24}$$

The last schedule method that (Vanhoucke, 2009) identifies is the earned schedule method introduced by Lipke (2003). This method utilizes an earned schedule metric that is calculated by mapping the EV at any point in time to the corresponding PV, thereby finding the time that the EV should have been realized according to the baseline plan values.

$$Find\ t\ such\ that\ EV\ \geq PV_t\ and\ EV\ < PV_{t+1}$$

$$ES = t + \frac{EV - PV_t}{PV_{t+1} - PV_t} \qquad \text{Equation 25}$$

Where:

ES	Earned Schedule
EV	Earned Value at the actual time
PV_t	Planned Value at time instance t

In this technique, three forms of forecasting are proposed:

- Remaining work will go according to original plan.

$$Forecasted\ Duration\ at\ Completion = AD + PD - ES \qquad \text{Equation 26}$$

- Future work will follow the current schedule performance trend.

$$Forecasted\ Duration\ at\ Completion = \frac{PD}{SPI} \qquad \text{Equation 27}$$

- Future work will follow the Schedule-Cost performance trend (SCI) (cost and schedule both have an impact on the final duration and are inseparable).

$$Forecasted\ Duration\ at\ Completion = AD + \frac{PD - ED}{SCI} \qquad \text{Equation 28}$$

Vanhoucke (2009) goes on to demonstrate that the first two techniques are less reliable for measuring schedule performance due to the fact that traditional SV and SPI tend toward a performance index of 1 at the project completion. This renders forecasts using the first two techniques less and less accurate as the project approaches completion.

Two simple but useful performance metrics that arise from the earned schedule method are the Schedule Variance (SV(t)) and Schedule Performance Index (SPI(t))

$$SV(t) = ES - AT \qquad \text{Equation 29}$$

$$SPI(t) = ES / AT \qquad \text{Equation 30}$$

(Vanhoucke, 2009) assessed two very different forms of project controls for monitoring schedule performance: top-down tracking and bottom-up tracking.

Top-down tracking involves using EVM principles Schedule Performance Index SPI and Time Schedule Performance Index SPI(t) to measure performance at the project level and using performance thresholds to determine if corrective action is required and if drilling down into the detailed levels of the WBS is necessary.

Bottom-up tracking involves using the Schedule Risk Analysis technique at the activity level of the WBS to assess sensitivity of each activity to impact the project duration. This technique uses sensitivity thresholds to determine where and if management attention is required.

Through a series of Monte Carlo simulations, the author identifies that the SPI(t) method and the Schedule Risk Analysis technique are both effective means of monitoring schedule performance, while the traditional SPI technique has the lowest efficiency in nearly all the scenarios tested. The degree of parallel activities in a project versus the degree of serial activities was determined as the primary factor in deciding which method was more efficient. For highly parallel projects the Schedule Risk Analysis approach performed more efficiently than the SPI(t) and SPI. The opposite was true for highly serial projects.

Construction Industry Institute (1986) looked at schedule control specific to engineering work. It found that detailed schedule control for engineering deliverables and bar charts may be used, but for effective control, the roll-up from the lower levels must be to activities on the CPM-formatted schedule. It also noted that changes can only be made to the schedule based on approved changes. Actual performance was found to rarely follow the control schedule and so a working schedule is also to be maintained throughout the project: a detailed schedule used for planning near term work (30 to 90 days). Control schedule must be used to report performance.

Productivity Index = Sum of Earned Work-Hours of Tasks Included / Sum of Actual Work Hours of Tasks Included

SPI = sum of earned work-hours to date / sum of schedule work-hours to date.

SPI gives some indication of schedule performance but does not account for the critical path of the schedule. An SPI of over 1.0 could be calculated even when the project is at risk of overrun on the CPM schedule. Regular examination of the schedule is required (Construction Industry Institute, 1986).

2.3.5.2 Timing of Forecasting

Kerridge (1986) recommends using forecasting performance index of 1.0 when the project progress is less than 50% and using performance index of cumulative previous performance when the project is greater than 50% complete.

Particularly important is the forecasting undertaken within the first quarter of a project. This is the time where the decisions by management to correct poor performance have the most impact (Nasser, 2005).

For forecasting final outcomes, Lester (2006) suggests one of two formulae which will in the end give the same result:

- Dividing total actual man-hours used to date by total percent complete.
- Dividing total budgeted man-hours at completion by efficiency.

It should be noted that these techniques are calculated using rolled-up values of progress and/or EV from the individual tasks to the project level.

2.3.5.3 Forecasting at the Project Level – Rolling-Up the Forecasts

This study proposes the use of forecasting at individual tasks and rolling this up as a direct summation to get the total forecast at completion (Lester, 2006).

More sophisticated forecasting is based on sum of individual forecasts versus taking the rolled up progress multiplied by the actual man-hours/dollars (Lester, 2006).

Sums EV for calculating higher level PI does not jive with the forecast or variances roll-up (Eldin, 1991).

2.3.5.4 Performance Investigation and Corrective Action

The role of a proper EVM system is not only to identify the cost and schedule deviations from the plan, but also to investigate the causes and develop corrective actions. The following provides a brief review of the suggested approach to investigating performance and developing corrective actions.

Defense Contract Management Agency - DoD (2006) discusses the importance of the EVM analysis process involving an integrated team approach. "Analysis is a team effort – fully integrated into the overall program management process. Effective analysis considers all impacts, considers all courses of action, synthesizes an integrated solution and action plan, and allows informed decisions. The real test for effective, forward looking analysis is that it is used to manage program performance, not just to report the state and problems to date" (P. 62, Defense Contract Management Agency - DoD, 2006).

The following is suggested to be involved in analysis of EVM results:

- Checking validity of data.
- Calculating variances at all levels.
- Graphing analysis data.
- Comparing to existing data from the project and other projects.
- Analyzing schedule trends and critical path.
- Examining written analysis from responsible parties from each work-package.

Project Management Institute (2011) suggests a root cause analysis may need to be undertaken to identify the cause of performance deviations from the plan.

This EVM approach allows for "management by exception" where focus and effort are only applied where needed throughout the project, greatly increasing the efficiency of project management. The document does not, however, suggest how to go about this or what the performance thresholds should be to undergo this investigation.

Chang & Ibbs (2006) and Chang (2002) also emphasize the need to analyze cause-effect relationships more rigorously to gain insight into project performance. They imply that traditional control systems detect problems with cost and schedule but neglect to provide thorough investigation of the reasons for the problem and propose corrective actions.

Chang (2002) goes on to list the root causes of changes on the projects that were investigated. This included, among many others:

- owner requests,
- optimistic schedule,
- work omitted in original scope by owner,
- owners' failure,
- other consultants' or consultant inability,
- omissions or underestimates of the consultant, and
- other factors beyond the control of the owner.

Although not explicitly stated in this paper, the causes of changes on a project could create a starting point for guiding corrective action investigation. How to analyze the root causes of poor performance and select corrective actions depends on who can control the issues and this depends, at times, on the cause of the issue.

2.3.6 Reporting and Decision Making

There is little in the reviewed literature on reporting EVM that is specific to the design phase. In general, reporting EVA is simply a form by which the information is conveyed during the life of a project or to close it out. In practice, EVA results are generally reported using the performance indices and figures discussed in **Chapter 5.5** but there is no set format with which to present this information.

Research by Kuprenas (2003) did look into the frequency of reporting during the design phase of work and its impact on project performance. In this research, frequency of reporting progress was found to reduce design phase effort. The study of 270 projects found that measuring and reporting on progress one or more times per month had a significant positive relation to design phase cost performance when compared to having less than one per month.

Construction Industry Institute (1986) study of design phase project controls did not fully touch on the reporting requirements specific to a design phase, but mentioned that reporting should provide project management information needed for control of the project. This included conducting continual analysis to identify trends, trouble areas and implement corrective actions.

Vanhoucke (2009) emphasized the need for understandable dash-boards to visualize the important performance metrics and reveal information on time and cost performance to allow for timely corrective action. This can be accomplished through the setting of performance thresholds to trigger management attention. For example, if cost performance drops below 0.8 efficiency, management needs to look into the details and determine how to bring the project back on track.

Project Management Institute (2011) states that the level of detail and type of information that is reported varies considerably depending on the audience. The client may only wish to see the overall status of the project in terms of the forecasted cost. On the other hand the project manager would generally want to see more of the details of the individual control accounts to allow for proper management and pinpointing of poor performance. To this end, a variety of techniques are provided in the EVM standard. These include but are not limited to:

- Data Tables.
- Bar charts.
- S-curves.

These data tables are capable of providing the more detailed results for varying levels of detail on the WBS. They would generally list the typical EVM indices and forecast information for each control account or higher level summary account.

Bar charts can be useful in comparing PV to EV or AC to EV on a period-by-period basis.

S-curves are the traditional visual tool for EVM. These charts compare the cumulative PV over the life of the project to the cumulative EV and AC to date. This figure can, at a glance, communicate the current health of the project.

Lester (2006) demonstrated the use of actual percent complete versus planned percent complete curves. They are seen to be more revealing of performance than looking at actual hours expended versus planned hours expended, and can be used as a good indicator of whether the hours spent were useful or not. This technique is taken a step further in Project Management Institute (2011), where comparing percentage of work complete, work-planned, and AC can be a rather intuitive form to communicate status.

Of particular interest is the suggestion by Project Management Institute (2011) to look at two values for AC percentage. One is the percent of AC spent compared to the latest estimate at completion. The other is comparing the same percent spent but this time to the current budget at completion. The former value can be seen as the more realistic percentage spent of the AC that are expected. This value could also be seen as the updated percent complete for the project — a percent complete that is congruent with the forecasting. The issue that has been observed throughout the development of this research is that the percent complete measured in the traditional sense (rolling up the weighted percent complete of individual control accounts) is often not congruent with the forecasting. The latter AC percentage compared to the current approved budget at completion is more useful in the comparison to earned percentage and planned percentage as it can give an intuitive view of where the project sits. Generally, looking at percentages can be more indicative of performance than looking at the actual values in terms or currency or man-hours.

The same source also promotes the use of a variance analysis report that is completed once a given control account deviates from the plan by a set amount. This report is generated as a result of investigation and root cause analysis into the variance and details of the causes, impacts, and corrective actions. Within the corrective actions, it lists the expected recovery date.

2.3.7 Review of Current Industry Practices for Controlling Engineering Work

It is one thing to look at the state of the art research in project controls for engineering work and an entirely different thing to see how it is actually done in practice. Due to a variety of reasons such as practicalities, lack of know-how, tradition in industry, or resource constraints that must be dealt with on actual projects, the degree to which state-of-the-art research is used in practice is limited. Project controls is not the primary focus for any project and nor should it be. The project is being implemented to satisfy a need (business, social, cultural, etc.) and is not undertaken for the purpose of implementing a project controls system. Often, the implementation of a project controls system can be seen as non-value adding or a necessary chore. Not surprisingly, actual practice typically takes a simpler, more practical approach to project controls. At times this approach is sufficient and the client is satisfied with the final outcome. On the other hand, if something does venture off course (budget is overrunning or schedule has slipped), the traditional approach shows its weakness. The client is often left in the dark or is provided a simplified version of the information where little conclusion can be drawn. There is substantial difficulty pinpointing what has gone off track, to what extent it has done so, and why.

Identifying the state of actual practice is important in establishing the areas of contribution of this thesis and exposing challenges that must be overcome in order to implement the proposed approach. For this reason, the next chapter provides a discussion of current practices using major transportation projects in the City of Edmonton. Information on project controls for engineering work on these projects is solicited from project documents and interviews with key project members. The projects investigated are shown in **Table 6**.

Table 6 – Projects investigated to determine current state of project controls for engineering work in practice.

Project Name	Phase	Engineering Budget Magnitude	Project Budget Magnitude
Transportation Project 1	Preliminary Design	Approximately $5M	Greater than $500M
Transportation Project 2	Detailed Design	Approximately $25M	Greater than $500M
Transportation Project 3	Construction	Approximately $30M	Greater than $500M

It should be noted that only official documents provided to the owner or project controls approaches and techniques that the owner was made aware of are considered in this chapter. Unofficial techniques that may have been used by the consultants to control their internal budgets were not considered as these are not formal project controls that form part of the official project management of the project.

2.3.7.1 Overarching Approach

In general, the approaches used to control engineering cost and schedule are provided below:

- Design Phase:
    - A basic work-package schedule (Gantt Chart) to the level of detail showing the start and end date for the major components of the engineering work.

    - Brief discussion of progress for major tasks documented in meeting minutes.
    - Budgets broken down to high-level cost accounts per design discipline (e.g. Project Management, Roads, Track, etc.).
    - Overall engineering contract cost status, detailing approved budgets and AC to date. No other comparison is provided.
- Construction Phase:
    - Brief explanation of engineering schedule progress per major construction contract.
    - Quarterly cost control reports showing engineering costs as one or two line items with approved budget, commitments, and AC to date.
    - Invoices showing similar information on a monthly basis.

The details of this information are broken down into the typical components of a project controls system in order to provide continuity between the various chapters in this document.

2.3.7.2 Baseline Development

The schedule for engineering work in design is broken down to the major work-packages, and in some cases detailed to one subsequent level. An example of this from Transportation Project 1 would be as shown in **Figure 5**. The breakdown provides timelines on most major deliverables for the design phase. This schedule is developed at the outset of the project to help guide the flow of work and satisfy the client that the project will meet the required milestones provided in the Request for Proposal. The schedule is not base-lined and tracked accordingly, showing updated finish dates for individual tasks and explaining any deviations. Typical progress lines for each task are not shown on the schedule.

The cost breakdown structure is not the same as, or integrated with, the schedule breakdown structure. In the proposal stage, the cost breakdown is generally to a second level WBS detail showing budgets for specific tasks related to a deliverable. This detailed breakdown, however, is often abandoned after the proposal stage and reverted to a high level cost breakdown for tracking purposes. The cost breakdown is generally to one or two levels of detail showing the major cost accounts such as Project Management, Track Design or Roads Design.

ID	Task Name	Duration	Start	Finish
73	**Track Alignment**	**80 days**	**Mon 09/06/01**	**Mon 09/09/21**
74	North Track (410+641.239 - 412+640)	50 days	Mon 09/06/01	Mon 09/08/10
75	South Track (310+667.352 - 313+425)	30 days	Tue 09/08/11	Mon 09/09/21
76	**23 Ave Grade Separation**	**80 days**	**Tue 09/08/04**	**Mon 09/11/23**
77	Direction to Proceed with Underpass Option	0 days	Tue 09/08/04	Tue 09/08/04
78	Design	80 days	Tue 09/08/04	Mon 09/11/23
79	**Ellerslie Station**	**120 days**	**Tue 09/08/04**	**Mon 10/01/18**
80	Decision on Location	0 days	Tue 09/08/04	Tue 09/08/04
81	Design	120 days	Tue 09/08/04	Mon 10/01/18
82	**O & M Facility**	**120 days**	**Tue 09/08/04**	**Mon 10/01/18**
83	Decision on Location	0 days	Tue 09/08/04	Tue 09/08/04
84	Design	120 days	Tue 09/08/04	Mon 10/01/18
85	**Bridge Structures**	**140 days**	**Mon 09/06/01**	**Mon 09/12/14**
86	Blackmud Cr.	95 days	Tue 09/08/04	Mon 09/12/14
87	AHD Overpass	105 days	Mon 09/06/01	Mon 09/10/26
88	**Track Structures (Ballast Curbs etc.)**	40 days	Tue 09/12/01	Mon 10/01/25
89	**Roadway/Pedestrian Modifications**	125 days	Tue 09/08/04	Mon 10/01/25
90	**Drainage**	50 days	Tue 09/11/17	Mon 10/01/25
91	**Utilities (Deep and Shallow)**	20 days	Tue 09/09/01	Mon 09/09/28
92	**Altalink Impacts**	80 days	Mon 09/06/01	Mon 09/09/21
93	**Systems**	**105 days**	**Tue 09/09/29**	**Mon 10/02/22**
94	LRT Systems Signals and Communications) - 8 New Locations	40 days	Tue 09/09/29	Mon 09/11/23
95	Traffic Signals - 4 Upgrade Locations	20 days	Tue 10/01/26	Mon 10/02/22
96	**Noise EMI and Landscape Architecture**	**140 days**	**Tue 09/08/04**	**Mon 10/02/15**
97	Noise and Vibration	30 days	Tue 09/08/04	Mon 09/09/14
98	Electro-Magnetic Interference (if required)	10 days	Mon 09/10/12	Fri 09/10/23
99	Landscape Architecture Design	15 days	Tue 10/01/26	Mon 10/02/15
100	**Traction Feed Power and Substations - 3 substations**	120 days	Tue 09/08/11	Mon 10/01/25
101	**Safety Audit**	20 days	Tue 10/01/26	Mon 10/02/22
102	**Public Consultation**	**161 days**	**Mon 09/06/01**	**Wed 10/01/13**
103	Stakeholders Information Panel	20 days	Mon 09/06/01	Fri 09/06/26
104	**Public Meetings:**	**70 days**	**Wed 09/10/07**	**Wed 10/01/13**
105	Open House #1	0 days	Wed 09/10/07	Wed 09/10/07
106	Open House #2	0 days	Wed 10/01/13	Wed 10/01/13
107	**Constructability and Staging Workshops with Peer Review Committee**	**16 days**	**Tue 09/12/15**	**Wed 10/01/06**
108	Workshop #1 - Project Delivery	0 days	Tue 09/12/15	Tue 09/12/15
109	Workshop #2 - Construction Staging Strategy	0 days	Wed 10/01/06	Wed 10/01/06

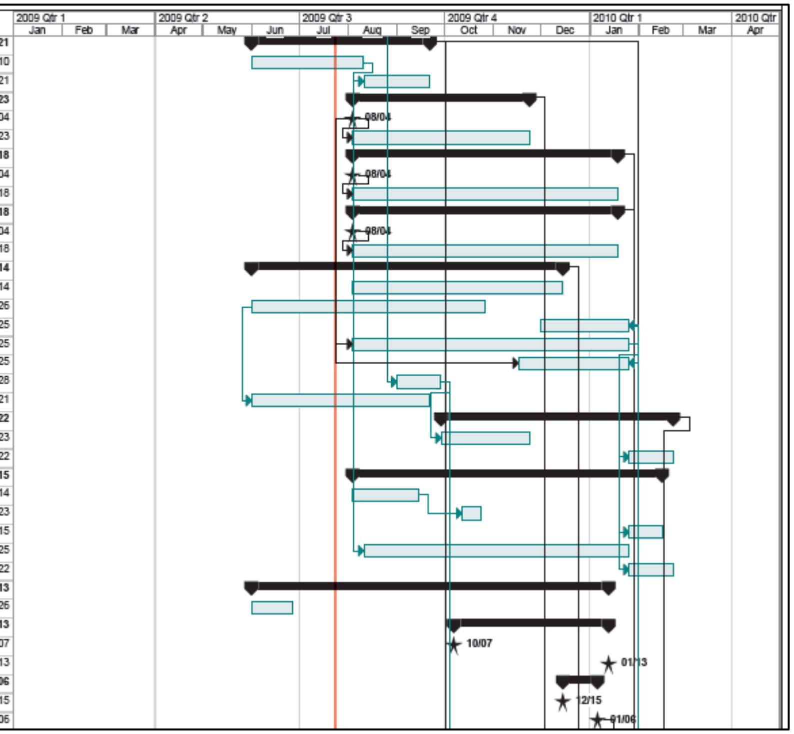

Figure 5 - Sample design schedule breakdown for Transportation Project 1

The only baseline that is used for tracking is the project milestones required by the client and the proposal budgets along with any approved change orders to either cost or schedule. The schedule baseline is not integrated with the cost baseline. This means there is no time-phasing of budget over schedule for tracking purposes. There are project level cash-flows provided to the owner for financing purposes, but this cash-flow is not part of project controls and the engineering team is not accountable to meet this cash-flow. There is no measure of the amount of budget or effort that is planned to be expended per budget account per period of measure. The only period of measure is the project as a whole. This means that the only point in time that the owner would know that a budget is in jeopardy of being overrun is when the cost account or project nears completion.

2.3.7.3 Baseline Maintenance

As mentioned previously, the baseline is separate for cost and schedule. The baseline for each is maintained by incorporating any approved changes to budget or schedule on the affected cost account or scheduled task.

2.3.7.4 Progress Measurement Techniques

Progress measurement is limited to subjective evaluation of progress in terms of started and complete work-packages. For example “Roads Design has started” or “Constructability Workshop completed.” The only record of this progress is in meeting discussions documented through meeting minutes. There is no formal progress measurement approach used to track physical project status or compare to AC on the projects that were reviewed. A project-level progress metric sometimes used is percent of budget spent. This does not represent a physical percent complete of the engineering work.

2.3.7.5 Performance, Forecasting and Corrective Action

There is no recorded analysis of the data, performance is not assessed in any structured fashion and forecasts are not provided based on any analytical information. One project did provide forecast information, but this was merely the budget plus approved changes.

Meetings and meeting minutes were used to discuss problem areas and assign actions to correct them, but there was no structured format for this.

2.3.7.6 Discussion

This review of current practices is only a snapshot of what is actually done in industry to control engineering work; however, the projects that were reviewed are engineering projects of significant size and complexity and were undertaken by major consulting firms. The literature in this area of project controls only confirms what is demonstrated in this case study. A representative study by Chang and Ibbs (1998) showed that control of engineering work has generally been relegated to simple controls such as progress reports, master schedule, detailed 4-week look-ahead schedules, and monthly accounting summaries (Chang & Ibbs, 1998).

These documents provide summary-level insight into what has happened to date, what is planned, and where costs have been incurred. They provide a relatively subjective overview of progress. They do not integrate cost and schedule, or measure physical progress. They do not provide a structured or analystical view of performance, nor do they offer substantiated forecasts of project end results. They do not provide a structured framework for controlling individual project components, nor do they offer adaquate prioritization of management attention. With these forms of project controls, the owner and management team are more susceptable to being left in the dark, or being caught by surpise when a budget is overrun, or a schedule slips. Often, end results of the project are not exposed until the project is nearing completion. Although some research has been conducted in this area to improve the current situation, the transfer of these techniques into practice has been slow and in some cases non-existent (Eldin 1988; Chang 1997).

2.4 Literature Review Summary

The body of knowledge in the area of project controls for construction work is extensive and only touched on briefly within this document. Primarily, the discussion related to EVM techniques that have been proven to work in the construction environment.

The bulk of the literature review focussed on the more specific topic of cost and schedule control in relation to engineering work. There were several studies that dealt with this topic explicitly and others that addressed advanced EVM techniques that can relate to controlling engineering work. It is noteworthy to point out that implementing EVM to control engineering work was addressed in several studies, and these techniques have been used to improve the proposed approach in this thesis. Of particular importance is the area of progress measurement and forecasting. Several techniques are discussed in literature for measuring progress and for forecasting, and this thesis builds and expands on these techniques, and offers practical tools to implement them in practice.

The following chapter contains the proposed approach for controlling engineering work.

3 PROJECT CONTROLS APPROACH FOR ENGINEERING WORK

To satisfy the need for improved project controls on engineering work, the EVM techniques that have traditionally been used in construction are adapted to control engineering work. This next section provides an in-depth discussion of the challenges with doing this and offers proposed solutions to overcome them. The key challenges to be addressed are:

- C1. Work-packaging, estimating, and scheduling to create an integrated cost and schedule baseline.
- C2. Determining the proper distribution of effort over time for engineering tasks.
- C3. Tracking and incorporating cost and schedule changes into the EVM baseline.
- C4. Establishing practical methods for measuring progress that encapsulates the entire engineering effort.
- C5. Planning engineering work and measuring progress during the construction phase.
- C6. Correctly allocating AC that are congruent with progress.
- C7. Prioritizing corrective actions for performance variances.
- C8. Forecasting that accounts for the relationship between cost and schedule, unique to engineering work in design and construction phases.
- C9. Gathering the required information to perform EVM in an accurate, efficient, and timely manner.
- C10. Reporting results visually and effectively to various levels of detail.

Each of these contains several more specific challenges, as will be demonstrated. Each of the following sub-sections is structured into two primary sections: (1) challenges with implementing on engineering work, and (2) proposed solutions. In some areas, the proposed solutions are adaptations of techniques currently offered in literature, but customized to engineering work. In other areas, the proposed solution offers new techniques that can be used to control engineering work.

In order to establish the layout of the project controls approach, the following flow-chart provides an overview of the key steps in the project controls process (**Figure 6**). Each of these topics will be addressed in a dedicated sub-section of this thesis. The process for each will be expanded as it is introduced in the sub-section.

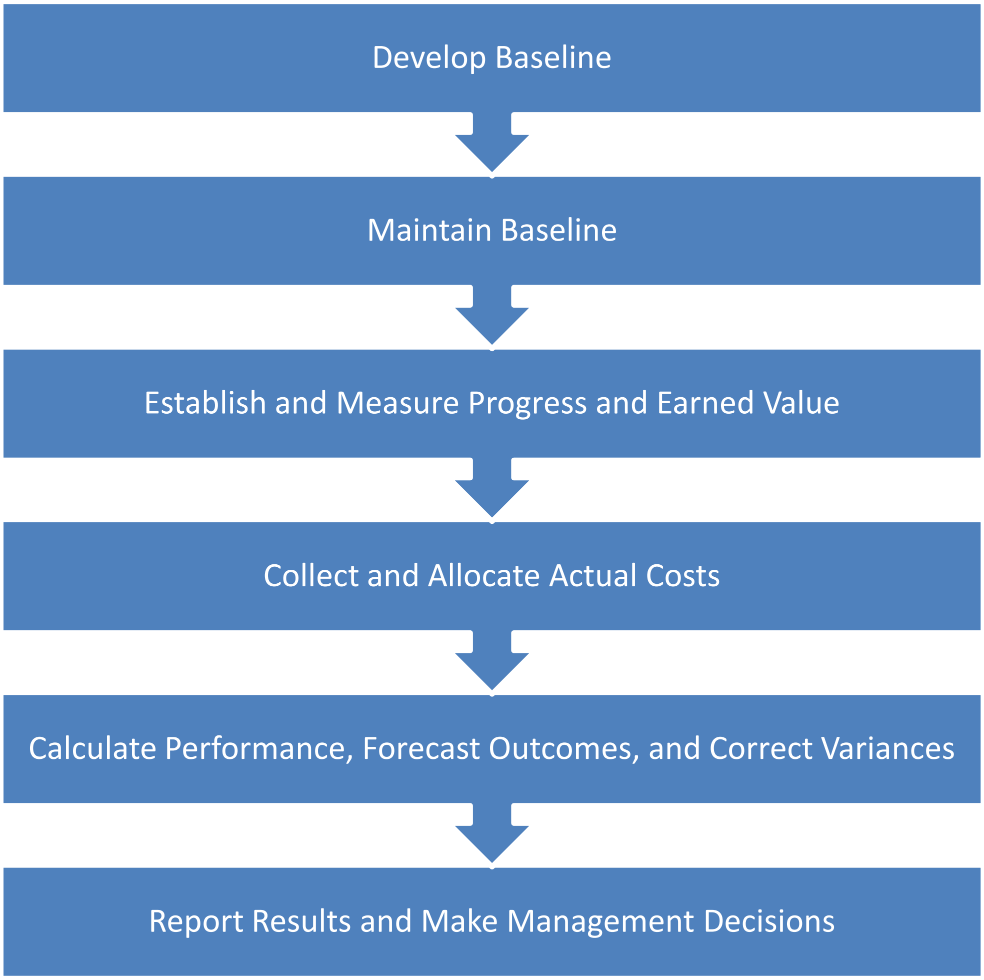

Figure 6 – Overview of proposed project controls approach.

3.1 Baseline Development

Baseline development in this context involves the steps required to set the foundations for an effective EVM system. This chapter details the requirements of the work breakdown structure, schedule, budget, and cash-flow in as much as they create the performance baseline from which work can be tracked and controlled against.

Baseline development for engineering work can be built off the proven techniques used for construction and other forms of projects, if it satisfies the issues discussed in the previous section. The proposed solution addresses each of these issues and recommends a reasonable solution to allow development of a baseline for performing EVM on engineering work. The proposed solution provides insight into the unique requirements for engineering work in both design and construction.

Figure 7 depicts the specific steps involved in baseline development. Each topic will be addressed in the proposed approach.

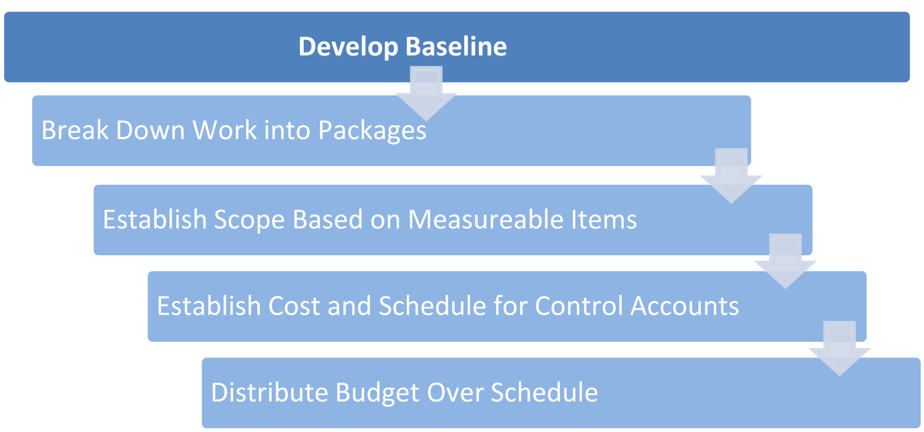

Figure 7 – Flow chart of the stages involved in baseline development.

3.1.1 Challenges with Implementing on Engineering Work

The following provides a discussion of the facets of engineering work that make baseline development unique. These challenges are important to overcome if the EVM approach to project controls is to be successful on engineering work. In the introduction, nine key challenges were raised; this section primarily addresses:

- C1. Work-packaging, estimating, and scheduling to create an integrated cost and schedule baseline.
- C2. Determining the proper distribution of effort over time for engineering tasks.
- C6. Planning engineering work and measuring progress during the construction phase.

Within these topics, the more specific challenges include:

a) Integrating cost and schedule structures.
b) Packaging work to optimize the effort required to implement EVM.
c) Using proposal budget and schedule to create the baseline.
d) Presence of less finite activities for scheduling (compared to construction activities).
e) Productivity and level of effort are variations by time of year, holiday seasons, etc.
f) Increased uncertainty in scope and plan of work.
g) Dependency on construction schedule and progress.

Further discussion of these challenges is provided below for clarity.

a) **Integrating cost and schedule structures:** Integrating cost and schedule is a pre-requisite to developing a baseline for EVM. This issue is not unique to engineering work, but is certainly more apparent in design than it is in construction. Even the study geared toward control of engineering work conducted by the Construction Industry Institute (1986) used separate cost and schedule work breakdown structures, as fully-integrated structures were unheard of. Having separate cost and schedule structures may be overcome in baseline development by extensive management effort to link budgets to schedules after the fact, but it is less easily overcome when it comes to controlling changes to the work. Lukas (2008) reviewed the top reasons why EVM is unsuccessful on any project, and an integrated cost and schedule WBS used by all parties involved in the project is a major cause.

b) **Packaging work to optimize the effort required to implement EVM:** The required effort to implement EVM in the design phase has to balance the benefit that it brings to the project. EVM in construction is under less scrutiny for balancing project controls effort and benefit due to size and scale of construction work versus engineering work. A reasonable number for engineering effort is around 10% of the total project cost. This introduces the need to have a more streamlined project controls system that places emphasis on ease of implementation.

c) **Using proposal budget and schedule to create the baseline:** Engineering work is often planned based on the proposal that is prepared to win the job. Proposal planning is often very rushed and estimated with winning the project in mind and not necessarily the way that the project is going to be run in the end. Also, proposal planning often involves personnel who will not necessarily be performing the work if the job is won. A key for project controls is assigning a responsible party for control of individual work-packages. If the responsible party is not involved in the planning, budgeting, scheduling of the work, it makes it difficult to hold them responsible for the performance of the work, thus increasing the likelihood of deviations from the plan during implementation. Control account manager or responsible party need to be comfortable with the cost estimate for each control account before it is approved (Project Management Institute, 2011). Having the responsible party buy into the budget and schedule that they are assigned to control is a step in the right direction for effective project controls.

d) Presence of less finite activities for scheduling (compared to construction activities): It is not simple to break a design project into as small and finite of activities as is the case for construction work. For example, an activity planned in construction such as "Pour Concrete" would generally be a day or two in length and could be scheduled and budgeted fairly accurately. Whereas in design a reasonable activity could be "Prepare 60% of Roadworks Design." This activity is on a much broader scale than the "Pour Concrete" activity, and would often take much more time than the construction example — depending on the size of the design it could be between 3 months to a year. An activity smaller than this in the design phase would be more difficult to schedule, budget, and control. An activity smaller than this is also less needed in design work as there is less activity interrelationships to account for and generally less companies and people involved than there is in construction. The result is that activities in design are often planned at a higher level of detail than construction work. This has a subsequent impact on the baseline used to perform EV calculations. The baseline in EVM is developed by distributing the budget for a particular activity over the schedule for that same activity. This gives a time-phased budget. The typical assumption that is made in order to develop the time-phased budget is uniform distribution of the budget over the schedule. That is to say that the budget is expected to be spent equally over each time division of the activity. This assumption is highly dependent on the duration on the activity in question: the shorter the activity, the better the assumption holds. In design, there is increased likelihood of activities having too long a duration for the uniform assumption to hold.

e) **Productivity and level of effort are variations by time of year, holiday seasons, etc:** Design work is often less immediate than its construction counterpart. In construction, there is less give in the schedule to accommodate holidays, weekend, vacations, stoppages in work, etc., than in design. This may be due to increased interdependencies and complexity of construction work where delaying one thing could have extensive consequences to many other activities. It may also be due to higher overhead costs for each day of construction work versus design phase work. Never-the-less, it is the author's experience that planning design phase work must account for periods of decreased productivity and spending around holidays, weekends, vacations, and depending on the time of year.

f) **Increased uncertainty in scope and plan of work:** Another hindrance in developing the EVM baseline is when the scope or plan for portions of the work are still uncertain at the time of baseline development. This would be the case in larger projects where there are significant uncertainties in scope, methods, funding, etc.. This is of particular importance in early design phase work, where the scope is still being defined. The baseline development needs to account for this uncertainty and offer a technique that allows for a streamlined approach to modify the baseline, and prevents significant re-working of the baseline as scope becomes defined.

g) **Dependency on construction schedule and progress:** In construction, developing a baseline is highly dependent on the construction work that is being monitored or inspected. The Engineer of Record (EOR) work is required when construction is being planned or construction is progressing. This means that the baseline for engineering work must be developed in conjunction with, or after, the plan for the construction work. It also means that the baseline must be flexible and responsive to changes in the construction schedule.

To address these challenges, the following approach is proposed for creating the EVM baseline.

3.1.2 Proposed Solution

3.1.2.1 Break Down Work into Packages

First and foremost, the project WBS must be established in such a way that it does not burden cost accounting with detail, yet allows the schedule the flexibility to go into further detail if required. The proposed approach is to establish the WBS based on the joint requirements of the cost structure and schedule structure. **Figure 8** displays this approach. First the WBS must be broken down into engineering disciplines (e.g. Roads discipline, track discipline, etc.). From there, it is necessary to divide the work between overall management work, and then the various unique design components of that discipline. For example, the Roads discipline during the design phase could be broken into the geographic areas (Southeast Roads Design, Downtown Roads Design, and West Roads Design) or a Structures Discipline could be broken down into the various unique structures to be designed (e.g. Downtown Tunnel Design, River Crossing Bridge Design, etc.). Overarching items on the project like Project Management, Project Controls, Risk Management, Workshops, etc. should be their own WBS accounts. The approach develops a two level WBS where the second level is the control accounts, where cost and schedule are integrated. This structure allows costs to easily be allocated (not too detailed) and the schedule can be built off of it.

The approach offered in literature to integrate cost and schedule is to establish the cost and schedule link at the level below the control account. The proposed approach suggests that cost and schedule are integrated at the control account level for engineering work because allocating costs to the level below creates undue effort with allocating AC to the proper accounts and is prone to mis-charges, which can be detrimental to EVM (as will be reiterated in Section 3.4 – Actual Costs). It is suggested that this approach allows for an easier integration of cost and schedule that reduces the effort required to plan and control the work. It should be noted that the WBS discussed here provides only the framework for the schedule; detailed schedule activities can be established subsequently from this framework.

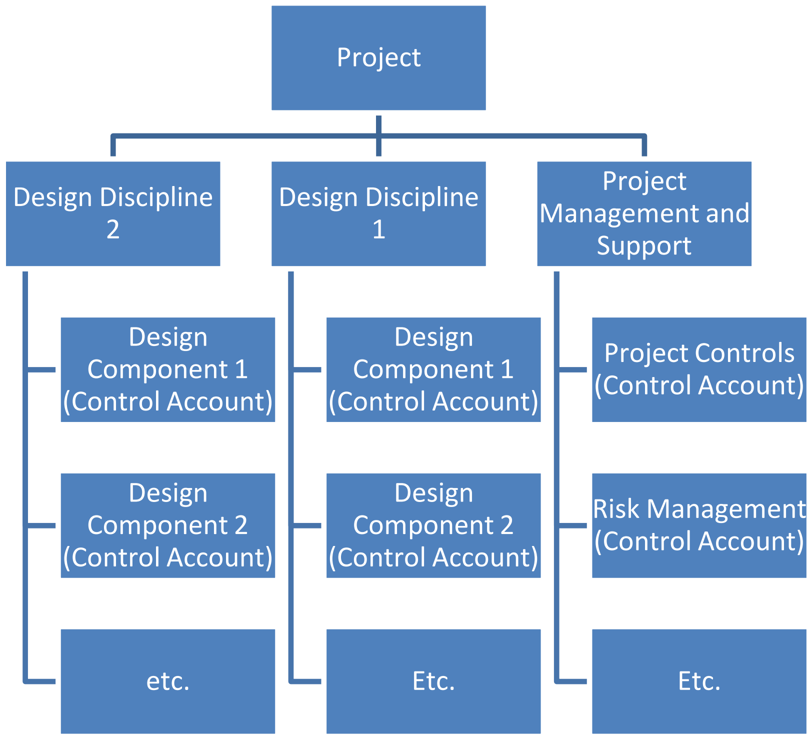

Figure 8 – Proposed structure of the WBS for design work

Once the WBS is developed to a sufficient level of detail, control accounts are established. These will form the work-packages to which cost and schedule are integrated and EVM is performed. The second level work-packages form the control accounts. This level of detail in a WBS allows enough precision for EVM to pinpoint where the project is deviating from the plan, but allows reporting to be summed up to either level 1 or project level. This optimizes the effort required to implement EVM on engineering work. Each control account should be assigned a manager that is responsible for controlling this work.

It should be noted that engineering work in construction need not go to the second level of detail for the control account. This allows it to be matched with the breakdown of construction work as will be seen in the next section where control account scope is determined.

3.1.2.2 Establish Scope Based on Measureable Items

The scope for each control account is determined based on the primary deliverables of engineering work. Because engineering work is different in design and construction, this is broken into two sections.

3.1.2.2.1 Design Phase

For design components, the scope is determined by four categories: (1) drawings, (2) specifications, (3) design reports, and (4) special studies. These deliverables have been selected because they are the primary deliverables of the design phase and easy to define. Special studies is added to this list to account for the studies or analysis that are undertaken but do not directly relate to the design report or drawings. Typically, these studies are prevalent in the earlier design stages when project scope is still being determined. **Figure 9** displays this.

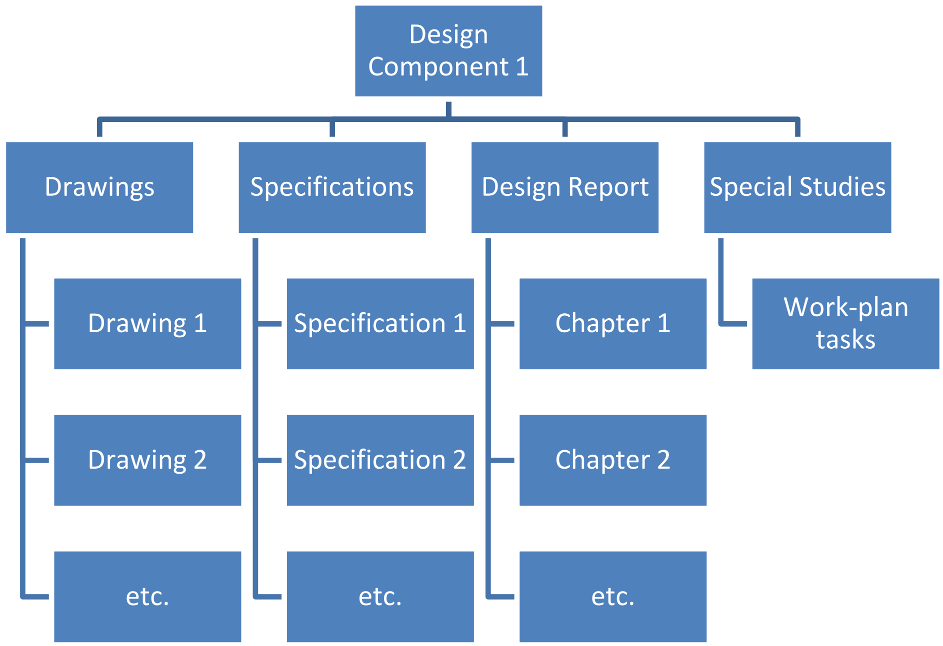

Figure 9 – Breakdown of scope for engineering work in design phase.

The scope for each of the four deliverable types is determined as shown in **Figure 9**. Drawings and specifications are simply comprised of the list of each that will be produced. The design report is broken into the standard chapters/sections that will be developed. Special study deliverables, as well as the size of the study, may vary. The scope for these studies is best established by work-plan tasks. These tasks would outline the necessary steps that will be undertaken. In some cases, it may be difficult or overly cumbersome to determine all the drawings that will be produced. In this case, it may be okay for some disciplines to create a list of drawing types to be produced instead of individual drawings. For example, a road design could be broken into profile drawings, elevation drawings, roll-plan drawings, etc.

3.1.2.2.2 Construction Phase

The construction phase requires a change to the WBS used for design work because it does not have the same scope and needs to be flexible enough to match the construction schedule and breakdown. In this case, the control accounts are established at level 1 (design disciplines). The scope of can be divided into four categories as shown in **Figure 10**: (1) monitoring, (2) contract administration, (3) record drawings, and (4) design modifications.

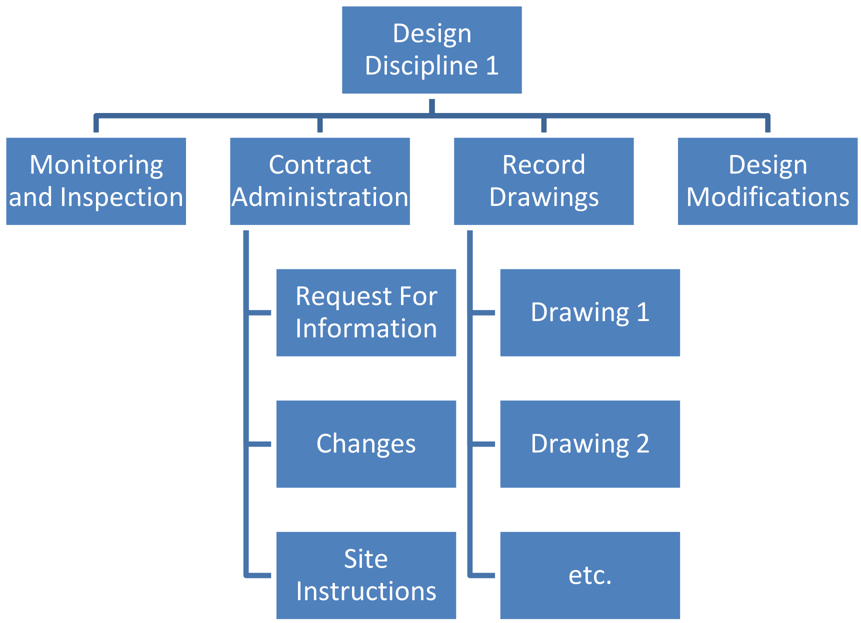

Figure 10 –Breakdown of scope for Engineering work in construction phase.

Monitoring and inspection is the engineering work related to being present on the worksite, attending meetings, inspecting quality, and documenting the work. Contract administration relates to the effort required to communicate and respond to requests for information, issue site instruction, and track and facilitate change management. Record drawing work is the part of the engineering scope related to developing the as-built record of construction. Design modifications scope is variable and accounts for any work involved in making changes to the design that arise due to innovations or constructability issues during construction.

For design and construction, establishing the scope as shown facilitates the next step in the process where costs and schedules are developed for each control account.

3.1.2.3 Establish Cost and Schedule for Control Accounts

3.1.2.3.1 Design Phase

This involves assigning cost and schedule for each control account on the WBS. For engineering work cost and schedule is preliminarily set based on the proposal used to win the engineering contract. As mentioned in the issues for baseline development, this proposal cost and schedule should be revisited by the control account manager. The scope of work detailed in the previous section should be used to further resource and plan the work. Any discrepancy or unclear areas between the proposal budget and schedule should be identified and resolved before the baseline is developed for this item.

For refining the budget, the control account manager reviews the proposed budget for each control account and refines the estimate to reflect how the work will be performed based on the defined scope. This is done for all control accounts on the WBS and the refined project budget is reconciled with the original proposal budget. Any discrepancy between the two is worked out on a case-by-case basis for each control account by project management. In the end, the control account manager needs to have some level of comfort and understanding of the budget that they are assigned to control. Once this is complete, the budgets for each control account are added to the WBS.

The same occurs for the schedule. The control account manager reviews the schedule for each control account and refines the durations and interdependencies with all other activities on the project. If necessary, the control account can be broken into further detail for scheduling purposes. The scheduled start and end date of the control account is determined by the earliest starting and latest finishing tasks underneath it. The critical path schedule is compiled by a central scheduling group, and once it is fully developed, final durations are communicated back to all responsible parties. These refined durations are then used to develop the EVM baseline.

3.1.2.3.2 Construction Phase

The baseline for engineering work in construction is highly dependent on the schedule for the actual construction work. The engineer's EVM baseline therefore must be linked to the construction schedule. The approach used to accomplish this is to integrate the engineer's baseline with the work-packages on the construction WBS. The proposed steps are discussed below:

- For each engineering discipline or EOR team on the project, identify the applicable construction work-packages from the construction WBS.
- Each discipline then looks into the schedule and planned effort that is expected for the relevant construction work and plans out their budget over time based on this information. The recommended approach is to assign and plan the engineering budget effort to each construction work-package individually (refer to **Figure 11**).

As will be discussed later in Section 3.2, this approach facilitates baseline maintenance during construction. When approved changes are made to the construction baseline, these changes can be reflected easily on the engineer's baseline. This technique allows transparency in planned budget expenditures from the engineering team, and allows for proper justification of increased or decreased budget as a result of changes in the construction schedule. This will be discussed as a challenge to overcome.

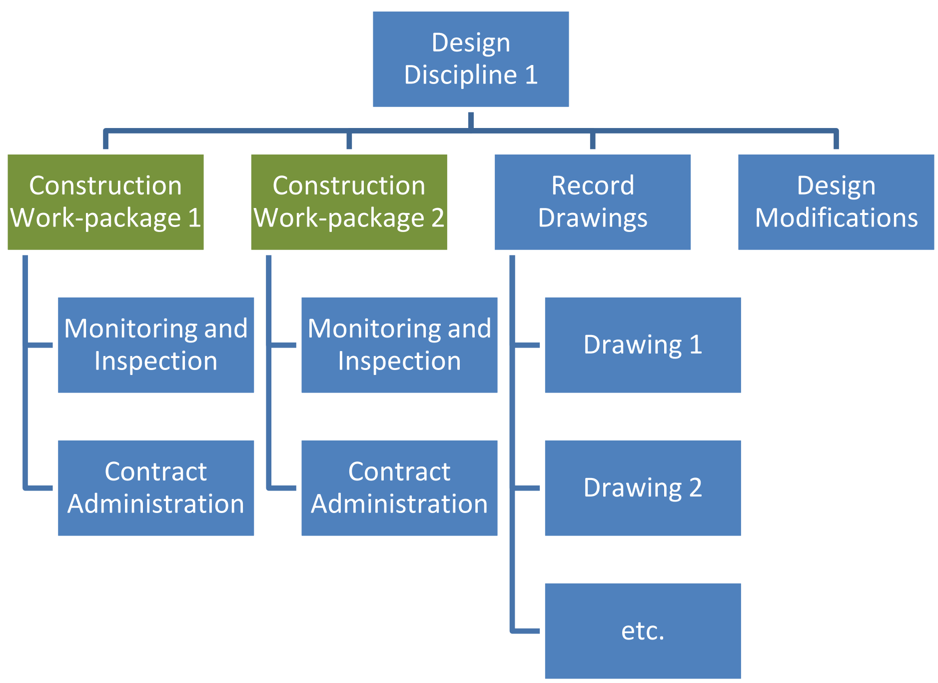

Figure 11 – Demonstration of Linking the Construction work-packages to the engineers WBS for planning the EVM baseline.

3.1.2.4 Distribute Budget over Schedule

The key to developing the EVM baseline is to distribute the budget for each control account over its schedule in as realistic a representation of effort as possible. For design phase, this is particularly important due to the higher degree of sensitivity of the baseline to holidays, weekends, vacations, times of year, etc., as well as the tendency for activities used to plan engineering work to be of a longer duration and less specific nature than those used to plan construction work. This research proposes the use of an automated control period weight calculator to help distribute the budget over the schedule. The control period is defined as the time periods used to divide the project for control purposes (e.g. a month is a control period). Each period becomes, in essence, a miniature project in itself with a planned budget, actual progress, and AC.

3.1.2.4.1 Control Period Weights

This research proposes the use of a customized control period weight calculator to distribute budget over schedule. An automated computer program, developed as part of this research, is used to perform this work. The program builds the initial period weights through input on:

- the desired control period to use for project controls (e.g. month, week, quarter),
- the work-week (e.g. Monday to Friday),
- statutory holidays,
- typical vacation months (e.g. December and August), and
- periods of historic reduction in effort and productivity.

With this input, the number of working days is calculated individually for each control period over the life of the project. By dividing the number of working days in each period by the total working days using the formula:

$$W_{period\ i} = \frac{WD_{period}}{WD_{total}} \qquad \text{Equation 31}$$

where: W_{period} is the weight for a given period i,

WD_{period} is the working days in period i, and

WD_{total} is the total number of working days for the project,

the period weight is calculated for each control period on the project. This sets the initial base for distributing the budget for the schedule.

The next step is to account for the start date and end date of the control account. Most control accounts will start and/or end at a date falling within a control period (not the start or end points of the period). This means that the full period's weight for the starting and ending periods will not have full effort allocated. For example, if months were being used for control periods and an activity started on September 15, it would only have about half the working days in that month. This activity should then only have half the period weight for that month when budget is distributed over the schedule.

The final step is to customize the period weights for each control account. As discussed previously, the typical assumption for distributing budget over schedule is to use uniform distribution. This assumption is best suited for activities with relatively short durations, typically no more than 4 weeks. In design phase, planning to this level of detail is often unrealistic and would require more effort to plan and control than the value it would add to project controls. For this reason, an alternate approach is proposed that accounts for the expected distribution of effort for a given control account. A set of standard distribution types are used to account for the level of effort that is expected for each control period. These are:

- Uniform Distribution
- Front End Loaded Distribution
- Back End Loaded Distribution
- Center Loaded Distribution
- Variable (custom) Distribution

Using these distributions, the budget can be distributed over the schedule using the distribution that best fits the effort profile for a given control account. A discussion of the different distributions is provided below.

Uniform Distribution

This is used when the effort on the task is relatively consistent over the schedule for that task. For example, activities that are relatively short in duration (up to 2 periods in length), or management-based activities which are on-going throughout the project.

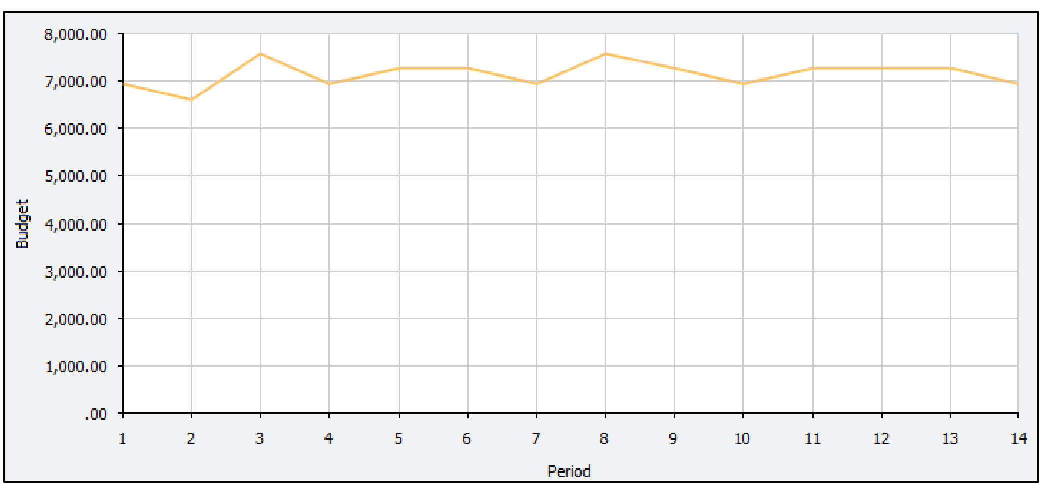

Figure 12 – Uniform Distribution.

Front End Loaded Distribution

This is used when effort for the task is predominantly at the beginning of the schedule for the task. An example could be risk management on a project. Initial risk analysis and major workshops are held at the beginning of the project, requiring a large portion of the overall effort, and effort tapers off as the project extends for risk control.

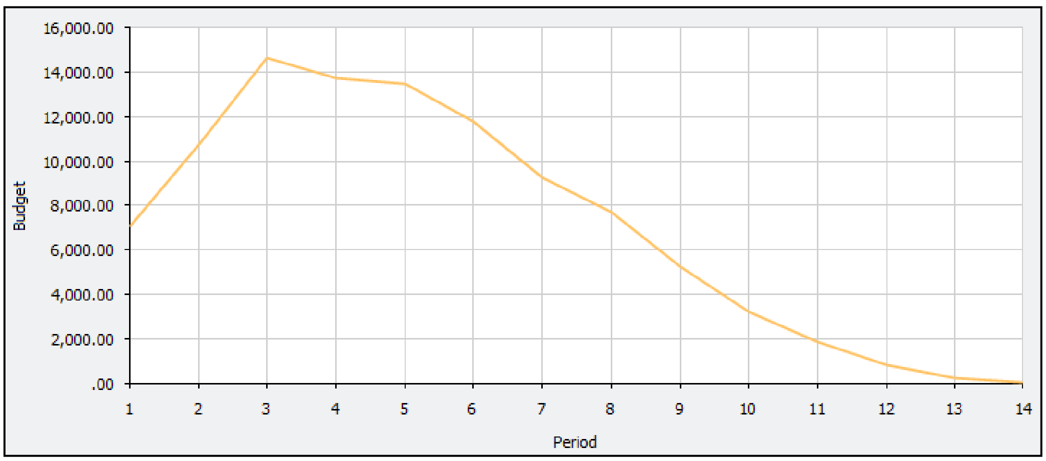

Figure 13 – Front End Loaded Distribution.

Back End Loaded Distribution

This type of distribution is used for tasks that contain a higher level of effort towards the end of the schedule. Typical examples of this are road works, where increased effort and costs take place as the final asphalt is poured. For engineering work this could depict a design effort leading up to a design review (e.g. 70% design review). Effort is slow at the start as scope is developed and requirements are established, and then picks up considerably towards the end as the designer prepare submittals for review.

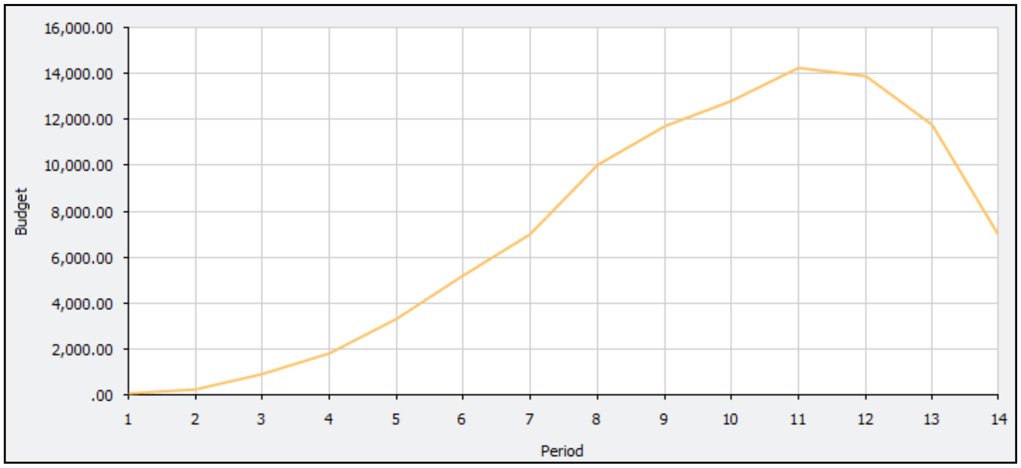

Figure 14 – Back-end loaded distribution

Center Loaded Distribution

A center loaded distribution type is used when work starts slower, accelerates in the mid-section and then tappers off again at the end. This is typically the case where a task has many sub activities underneath it. The more activities underneath it, the more likely it will have this distribution. A cumulative version of this distribution is the well-known ‘S-Curve’. The S-Curve is a standard PV curve at the project level.

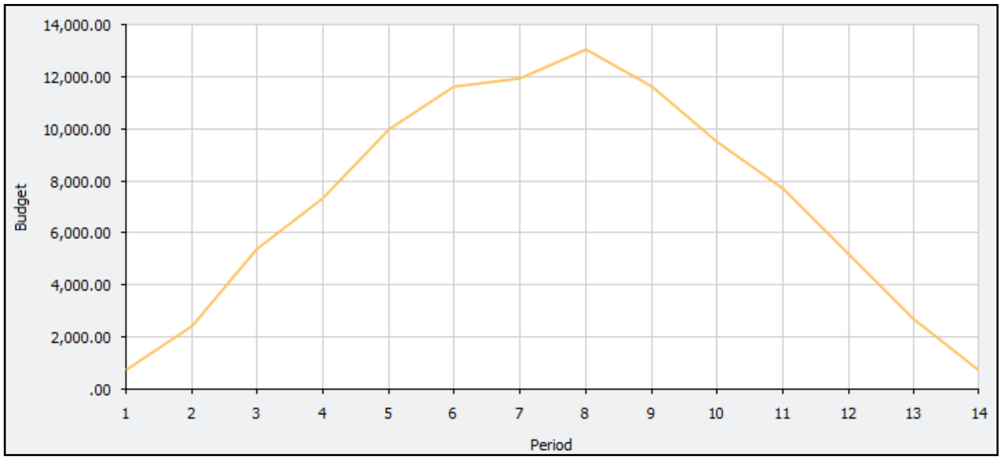

Figure 15 – Center Loaded Distribution

Variable (Custom) Distribution

The variable distribution is added to account for the tasks that cannot fit into any of the above distributions. This type of distribution allows the flexibility to specify, in more exact terms, the expected level of effort for any task. It can be customized to suit any type of effort profile.

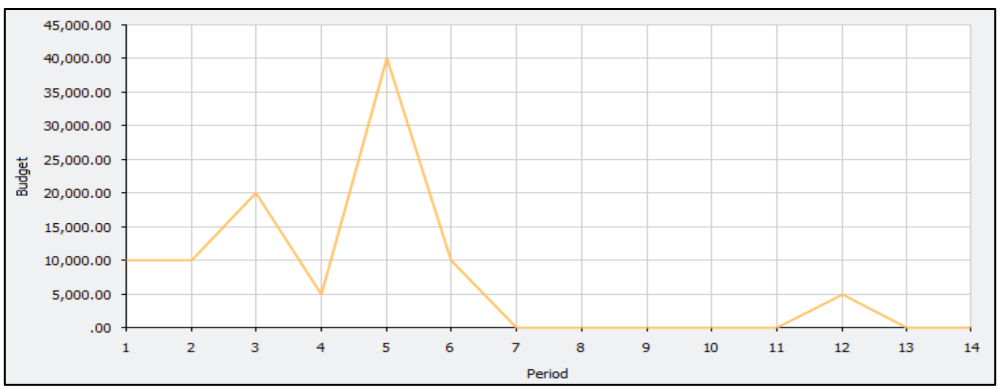

Figure 16 – Variable distribution

These distributions allow for an effective baseline to be developed when using a breakdown of work that is at a higher level of detail than those used for typical EVM in construction. It can account for the expected level of effort for a task that would otherwise require more detailed activity definition.

3.1.2.4.2 Rolling Wave Planning

At times, during the design phase, work progresses in phases, with one phase setting the stage and scope for the next phase. In this approach, it is difficult to plan too far ahead because the plan is subject to change. To account for this, the Defence Contract Management Agency – DoD (2006) and Project Management Institute (2011) recommend a method for developing the EVM baseline using "Rolling Wave" planning. This involves detailing the plan (budget over time) for work-packages that will occur in the near future, or for the first major milestone of the project, and leaving budgets and schedule for later activities in higher levels of the WBS. This research adopts this approach and takes it one step further. Instead of leaving un-planned budget in higher WBS accounts, it is proposed to allocate all expected budget to the control accounts for control purposes (though the project is not necessarily committed to this budget), and detail out the EVM baseline in milestone segments. The immediate milestone would be planned in detail using the approach discussed above, and the remaining budget would be evenly distributed over the remainder of the schedule for that account. As the next milestone approaches, the PV would then be detailed to a greater extent, and again the remaining budget re-distributed over the remaining schedule.

During early design phases, the uncertainty of scope is particularly high. A design team may not know which direction to move forward with, but may know what needs to be done in the near future to be able to clarify the scope. In these circumstances, it may be necessary to develop the EVM baseline using the rolling wave approach in conjunction with a more detailed milestone-based work-plan approach. Simple distribution of the budget over the schedule using the above distribution methods would suffer inaccuracies because the flow of work during earlier design phases is less consistent, and it is the author's experience that this work tends to fluctuate more erratically. The technique to account for this situation requires detailed work-plans to be developed for periodic milestones of the design. Using the rolling wave approach, the PV for each control account is detailed for the immediate milestone period using work-plans to one level of detail lower on the WBS than the control account. Again, the remaining budget is distributed over the remaining schedule for each control account. This is repeated as the next milestone approaches. It should be noted that these milestones need not be predefined. The milestone periods can be set as they are approached.

3.1.3 Summary Discussion

This section discussed the requirements for baseline development in performing EVM on engineering work. The key challenges that were sought out to be addressed are overcome in this proposed approach, the details of which are summarized below.

C1. Work-packaging, estimating, and scheduling to create an integrated cost and schedule baseline:

Solution offered:

- A structured approach to breaking down engineering work that facilitates planning and progress measurement based on measurable scope/deliverables.
- A technique for creating a fully integrated cost and schedule WBS that is flexible to the unique requirements of both structures and allows for ease

of baseline adjustment when budget or schedule changes are made. Integrating cost and schedule structures has long been a barrier for EVM. EVM standards do not specify that the cost and schedule be built to the same structure, they merely state that these structures must be linked. This linking can be laborious and error ridden and does not allow for easy up-keep of the baseline when changes are made to cost or schedule. This research offers a solution to this issue.

- Recommendations to refine and re-plan budgets and schedules for the engineering effort after the proposal stage of a project. The traditional approach in industry is to use the proposal budgets and schedules to create the baseline, but this often does not reflect the realistic plan for the work. In order for EVM to be successful on engineering work, a refinement of this plan is necessary, and should involve the managers and engineers that will actually be conducting the work.

C2. Determining the proper distribution of effort over time for engineering tasks:

Solution offered:

- A technique for distributing budget over schedule for any work-package based on control period effort weightings. For any work-package, the level of effort expected in any one period is held as an effort weighting from 0 to 1 instead of a unit of measure (e.g. currency or labour hours). This allows for simple adjustment to the PVs for each period when changes are made to the budget for that work-package.

- Preset distributions (uniform, front end loaded, back end loaded, center loaded, variable) for baseline cash-flow development (PVs) on engineering work or any other type of work that does not contain schedule and budget integration at a detailed activity level. The typical EVM approach is to use uniform distribution of the budget over the schedule for a given work-package to create the PVs. This technique works well when the work-package is relatively short or is consistent in nature. Engineering work is rarely broken down to enough detail to allow this assumption to hold. This technique to create the EVM baseline makes it more versatile and reduces the effort needed to implement the system.

C5. Planning engineering work and measuring progress during the construction phase:

Solution offered:

- A technique for developing engineer's baseline during construction phase of a project that is linked to construction WBS, budget, and schedule. Engineering work in construction is highly dependent on the construction schedule and progress. This research proposes a structured technique to link engineering baseline development to the construction baseline and facilitates baseline up-keep when changes to the construction work occur.

The next section will go into more detail on keeping this baseline up-to date throughout the life of a project.

3.2 Baseline Maintenance

Maintaining the baseline is a very important aspect of EVM. This process involves the continued refining of the baseline as approved changes are made to the project scope, schedule, and/or budget. **Figure 17** demonstrates the primary functions involved in this process.

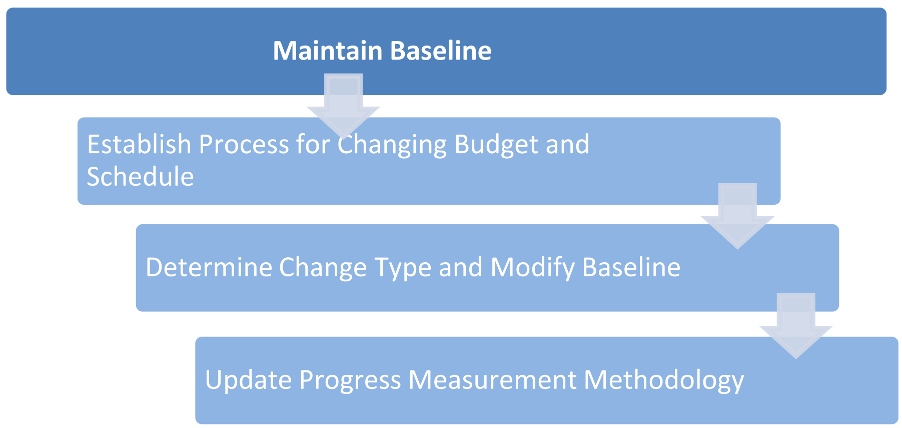

Figure 17 - Flow chart of the stages involved in baseline maintenance.

These components will be addressed in the sub-sections of the proposed approach. But before getting into the solution, it is necessary to identify the challenges with maintaining the EVM baseline for design work.

3.2.1 Challenges to Implementing on Engineering Work

The key challenge discussed in the introduction that is addressed in this section is:

- C3. Tracking and incorporating cost and schedule changes into the EVM baseline

This involves several more specific challenges including:

a) Linking cost, schedule, and scope changes with the EVM baseline maintenance.
b) Identifying and tracking design schedule changes.
c) Handling retroactive changes (changes that apply in past reporting periods).
d) Accounting for construction schedule changes on engineering EVM baseline changes.
e) Linking baseline adjustments to progress measurement

These challenges are discussed in more detail below for clarity and to set the context for the proposed solution.

a) **Linking cost, schedule, and scope changes with the EVM baseline maintenance:** Change management is a critical process in any design and construction project. It tracks any approved changes to scope, cost, and schedule on a project. Generally, the change management processes are separate from the EVM baseline maintenance processes and when it comes time to adjust the baseline with approved changes, the required information is not readily available. In order for EVM baseline maintenance to be effective, timely, and efficient, it needs to be directly tied into these change management processes. All required information to make the adjustments to the EVM baseline should be provided through the change management processes.
b) **Identifying and tracking design schedule changes:** Schedule in design work is less scrutinized and in some ways also less relied upon. The schedule in design has a tendency to be treated more as a guide to show critical milestones than a day-to-day and week-to-week planning tool. In

construction, the idea of a baseline schedule is contractually binding, and the contractor would be held to that schedule unless approved changes are made through a formal change order process. In design, schedule change orders are often only required for major milestone dates and the design schedule can be changed without need for approval unless it impacts the contractual milestone dates. Since the EVM baseline is directly dependent on the schedule, this creates difficulty with deciding when to update the EVM baseline. For construction work, a change order which approves a schedule change will effect an EVM baseline change. In design, with less rigorous schedule control, an EVM baseline maintenance process is required to determine when the baseline should be changed.

c) **Handling retroactive changes:** At times, changes to scope are approved and budgets and schedules adjusted after the fact. This creates problems for EVM. The EVM performance indices are generally cumulative metrics and if the adjustments to the baseline are not made at the time the AC or progresses are made, these indices will be skewed. Most EVM standards specify that retroactive changes need to be accounted for in baseline management, but the practical techniques to perform this work are not readily available in literature. Baseline maintenance can be an extensive task to undertake and handling retroactive changes makes this even more burdensome. If baseline maintenance cannot be performed in an efficient and effective manner, it will be less used in industry, and the corresponding EVM will be less effective. This cycle inevitably contributes to reduced use of project controls systems such as EVM. This research offers a structured approach to baseline maintenance.

d) **Accounting for construction schedule changes on engineering EVM baseline changes:** As mentioned previously, the engineer's EVM baseline during construction is directly linked to the construction schedule. This means that if the construction schedule undergoes approved changes, the engineer's EVM baseline must also be changed accordingly.

e) Linking baseline adjustments to progress measurement: A little discussed issue with changing the EVM baseline is the impact that these changes have on EV progress measurement. If a significant scope change is made to an existing control account, the progress measurement technique for that account must be revised to account for that additional scope. At times, budgets changes are made without significant scope change to account for inadequate budget estimating. For these changes, an adjustment to the progress measurement is required. However, if the change is simply added to an existing control account and the progress measurement is dependent on the scope of the account, it is obvious to see that a subsequent updating of the progress measurement technique is required. If the change is added as a new control account to the project, a progress measurement technique must be established for this new scope.

3.2.2 Proposed Solution

The proposed approach for baseline maintenance for engineering work in design and construction builds off of the same baseline development methods discussed in Section 3.1. The concept of using control period weights is used to facilitate baseline changes.

For each control account on the WBS, the previous section developed period weights to be used to distribute the budget over the schedule. This is extended to handle baseline changes whether they are retroactive, future, or present changes.

3.2.2.1 Establish Process for Changing Budget and Schedule

The first step in maintaining the baseline is establishing a process to document and control budget and schedule changes on the project. This must be established at the outset of the project, and strictly enforced. It should be noted that these changes are not limited to approved changes for the project as a whole, but also accounts for internal budget changes from one control account to another, and schedule changes modify control account schedules significantly. As noted above, change control in design is not dealt with to the same level of rigor as it is for construction. Often, schedule changes are not captured unless they modify the project end date and internal budget can often be shifted from one task to another. This is overcome by establishing a formal process for tracking all changes — internal and external.

The natural solution for this is to create a link to existing change management processes that are utilized on most design and construction projects. A typical change order would require the following information to be provided:

- Description of change and reasoning.
- Budget impact including breakdown of costs.
- Schedule impact.

The proposed addition to this process is to request on the same change order form:

- Control accounts impacted by the change or control account to be added to WBS.
- Budget impact to each control account.
- Schedule impact to each control account.
- Distribution method for budget over schedule.

If these additional items are added to the existing change management forms, the EVM baseline can be adjusted accurately and without excessive burdening to other project management processes.

With this information, the required adjustments can be made to the EVM baseline to keep it up-to date and an accurate reflection of the current plan. Including these requirements into the change management process also emphasizes the importance and seriousness that the project is placing on the project controls — a key to successful project controls implementation.

3.2.2.1.1 Construction Changes

In construction, the link to construction schedule and scope changes is important to address. In the previous section, it was shown that the WBS for engineering work should be integrated with the construction work-packages (refer to **Section 3.1**). When this is done, the changes to the engineer's WBS correspond with the changes to the construction schedule. Without this link, EVM baseline for engineering work in construction phase is very difficult to maintain.

3.2.2.2 Determine Change Type and Modify Baseline

Firstly, it is important to understand the types of changes that can be made on a project. In order to automate the change management process, this research proposes that there are four types of changes:

- Budget change to existing control account over entire schedule.
- Budget change to existing control account over specified time period.
- Schedule change to existing control account.
- Additional control account (additional scope).

3.2.2.2.1 Budget Change to Existing Control Account over Entire Schedule

This type of change accounts for the circumstance where the original budget for an account is either obviously insufficient or excessive for the work within that control account. This change would impact EVM calculation from the scheduled start of the account through to the finish. This is a form of retroactive change. The process to perform this change is a simple adjustment of the total budget for the account. There would be no change to the period weightings. The period weightings would recalculate the budget allocated to each period based on workings days, and the selected budget distribution method for the control account (uniform, front end, back end, center, or variable). In this way the only required information for this change is the revised budget for the control account.

3.2.2.2.2 Budget Change to Existing Control Account over Specified Time Period

This type of change is a more general version of the budget change over the entire schedule and accounts for the circumstance where a budget change has been approved for an existing control account for added or removed scope. Generally, this would be minor added or removed scope that would not have a significant impact on the progress measurement techniques which will be discussed later in this document. This change would impact EVM calculations for the specified time frame, whether retroactive or not. The process to perform this change is to treat it as a subtask to the existing control account. The budget, scheduled start and end date, and desired distribution method are selected for the item. The budget is distributed over the schedule. The original budgets for each period are then added to the budget changes in each period and the period weights are re-calculated.

3.2.2.2.3 Schedule Change to Existing Control Account

This type of change accounts for the circumstance where only schedule is changed for an existing control account. This change impacts the distribution of the budget for the control account in question. The only information required to make this baseline change is the adjusted start date and/or end date. The revised date(s) are input, the period weights recalculated, and the budget redistributed. This will have an impact on EVM calculations for all periods for the control account and is another version of handling retroactive change.

3.2.2.2.4 Additional Control Account

This type of change accounts for the circumstance where additional scope is added and is significant enough to warrant the addition of a new control account. The baseline change process to be followed is the same as that used to create the initial EVM baseline. Create the control account on the project WBS, determine the distribution method, and distribute the budget over the schedule.

This type of change requires the most information in order to generate the proper baseline change. It requires the control account name, WBS identification number, budget, start date and end date, as well as the distribution method.

The following table (**Table 7**) summarizes the types of changes, required information, and process to make the change.

Table 7 – Types of EVM baseline changes and procedures to implement the change.

Change Type	**Information Requirements**	**Procedure**
Budget change to existing control account over entire schedule.	Revised budget.	Revise budget for control account and redistribute based on period weightings.
Budget change to existing control account over specified time period.	Budget change amount, start date and end date of change, and budget distribution method (front-end, back-end loaded etc.).	Distribute change over the specified periods according to the distribution method. Add the values in each period in the original baseline to the added values from the budget change. Re-calculate weights for each period.
Schedule change to existing control account.	Revised schedule start date and/or end date.	Recalculate period weights based on new schedule and current distribution method.
Additional control account.	Control account name, WBS code, budget, start date, end date, distribution method.	Add new account to WBS, create PVs per period based on budget, start date, end date, distribution method.

Traditional forms of incorporating changes into the EVM baseline do not readily account for the changes to existing control accounts when those change apply to specific periods of time (not over the entire control account schedule). The proposed approach offers a technique using control period weights that distributes only the budget change over the specified periods and then updates the control account period weights.

3.2.2.3 Update Progress Measurement Methodology

Considering the four types of changes proposed, the progress measurement implications are unique for each.

- For budget change to existing control accounts, the progress measurement for that control account is to be revised to account for any addition or subtraction of scope.
- If no scope is changed and only the budget is adjusted, progress measurement weights need not be adjusted.
- If schedule is adjusted, only progress measurement that is dependent on schedule needs adjustment.
- If a new control account is added an entirely new progress measurement for that account is required.

These changes have an impact of progress roll-up to higher levels of the WBS. Adjustment to progress measurement is dependent on the type of progress measurement established for a specific control account. Further details of changing progress measurement to account for EVM baseline changes are discussed in the next chapter.

3.2.3 Summary Discussion

The proposed solution offers various methods to overcome the challenges with maintaining an EVM baseline for engineering work. The key contributions of this section and how they have addressed a key challenge are provided below.

C3. Tracking and incorporating cost and schedule changes into the EVM baseline:

Solution offered:

- Integrating baseline maintenance requirements into the existing change management processes on engineering projects (e.g. change order processes). Traditional forms of change management for engineering work do not provide enough detail to incorporate changes into the baseline and do not capture internal shifts to schedule or budget. Following the proposed approach to maintaining the baseline adds structure and consistency to the process. The recommendation is made to document all approved cost and schedule changes to control accounts and gather all required information to modify the EVM baseline in the process.
- A list of types of changes and processes for incorporating these changes (including retroactive changes that impact EVM in previous periods) into the EVM baseline. Change management is often cited as a critical EVM component. This research offers a summary of the different types of changes that can occur and directions on how to incorporate this change into the EVM baseline.

- A technique for handling retroactive changes or changes that apply to a particular timeframe of an existing control account. Traditional forms of incorporating changes into the EVM baseline do not readily account for the changes to existing control accounts when those change apply to specific periods of time (not over the entire control account schedule). The proposed approach offers a technique using control period weights that distributes only the budget change over the specified periods and then updates the control account period weights.

The next section addresses the fundamental processes of progress measurement for engineering work.

3.3 Progress and Earned Value

Measuring progress is possibly the most important aspect of EVM. For engineering work, this topic has been addressed in literature extensively for construction work and many standards exist for measuring progress on different types of work. The steps involved in this process as it relates to engineering work are shown in **Figure 18**.

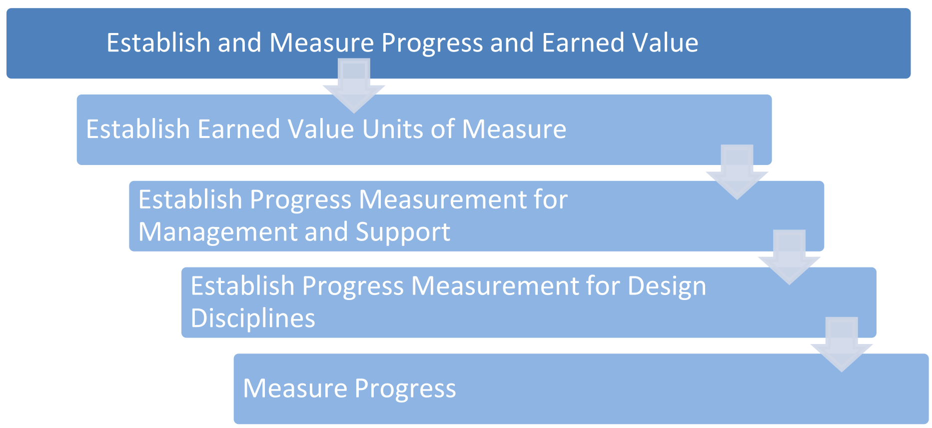

Figure 18 – Diagram of the different components of progress measurement for engineering work.

3.3.1 Challenge with Implementing on Engineering Work

The key challenge that is addressed in this section relates to:

- C4. Establishing practical methods for measuring progress that encapsulates the entire engineering effort.
- C5. Planning engineering work and measuring progress during the construction phase.

But more specifically, this challenge involves:

a) Work-hours versus currency for performing EVM.

b) Tracking entire scope of work (more than just drawings).

c) Different progress requirements for different phases of design work (differing levels of scope development).

d) Lack of measureable deliverables during construction phase.

Before these can be fully addressed, the background behind why these are challenges is provided.

a) Work-hours versus currency for performing EVM: EVM in construction is typically performed using units of currency; however, engineering work is estimated using work-hours. Hours are considered to be the primary unit of measure for engineering work as it is more intuitive to estimate hours on a drawing or other deliverables than dollars. EVM can handle either of these units of measure, but which is the most suitable to use?

b) Tracking entire scope of work (more than just drawings): As discussed in the literature review for progress measurement there is difficulty tracking progress for the full work scope for engineering work. Some literature suggested that tracking progress on supporting tasks such as management skews the EVM results. The tracking of drawings and other hard deliverables of engineering work has been tackled in literature and methods to perform this are offered (incremental and weighted milestones). Also noted in literature is that this work usually amounts to about 60% of the engineering effort (in terms of budget). It is obvious to see that the more work scope is progress is actually being tracked, the more accurate the EVM results will be. A method to track progress for supporting tasks such as management, quality control, running workshops, partnering, and project controls is necessary to improve EVM implementation on engineering work.

c) **Different progress requirements for different phases of design work (differing levels of scope development):** Engineering work is not one standard type of work. Different than construction work, engineering work spans the entire project life cycle from inception of the project, through concept, preliminary, detailed designs, and into construction. Each of these phases of engineering work has unique characteristics. It is easy to divide engineering work between design and construction, but when it comes to measuring progress and performing EVM during design, there needs to be further division between the different stages of design work. The level of work scope definition varies considerably through each phase of design. Design deliverables are different for the various phases of design. For this reason, using the standard EVM forms of progress measurement or even those techniques more suited to engineering work offered in in literature need to be customized to the type of engineering work in question. There is no one technique that will satisfy all phases of design work, and standard techniques will need to be implemented differently for the different phases of work.

d) Lack of measureable deliverables during construction phase: Further to the difficulties discussed above, engineering work in the construction phase is altogether a different type of work than design, involving more administration, monitoring, inspection, and documentation. Measuring progress for this work requires a very different approach than that used in design. In design there are clearly definable deliverables that can be identified and tracked accordingly. In construction, there is a significant decrease in clearly definable and track-able deliverables. As-built or Record drawings could be considered a deliverable of the construction phase but this is completely dependent on the completion of construction and accounts for a significantly less percent of engineering effort as drawings do in the design phase. Monitoring and inspection work requires a significant portion of engineering work during construction and does typically produce a deliverable in the form of daily or weekly reports, but these reports do not indicate progress for engineering work. For example, take a construction project that is planned to be 12 weeks long and the site engineer for this work is tasked with producing a weekly monitoring report. This means that 12 weekly reports are planned to be produced. A natural way to measure progress for the engineering work would be to track the number of reports completed. In this way, after 6 reports are completed, it would be concluded that the engineering work is 50% complete. What this technique fails to account for is the actual progress for the construction work that is being monitored. If the construction work is delayed by 2 weeks and the end date is moved back by this amount, the engineer's work would not be 50% complete but rather closer to 42% (6 completed reports / 14 required reports). What this example shows is that engineer work progress is highly dependent on the construction work that is being monitored. A method for tracking progress of engineering work during construction that is linked to construction progress is necessary to improve EVM implementation on engineering work.

3.3.2 Proposed Solution

3.3.2.1 Establish Earned Value Units of Measure

The two feasible options are hours or currency. When tracking costs and progress on engineering work, currency is more suited even though hours are the primary control item. This is because hours are not intrinsically what the owner cares about. The owner wants to see that the project will be on or under budget, and if it isn't, how much over will it be.

Engineering budgets are set by allocating a particular person at a particular hourly rate for a certain amount of time to perform a task. Often, these budgets are set in the proposal stage, and unfortunately, these resources are not always the one who in the end actually perform the work. If the person performing the work is at a different hourly rate, then tracking by hours would be ineffective. An example is used to demonstrate this. Referring to **Table 8**, assume that for a given task, the original plan was to have a \$150 per hour resource using 200 hours to perform the work. This gives a total budget of \$30 000. Now assume that the actual person performing the work had a 25% reduced hourly rate (\$112.50). In this case, after the task was 100% complete and the total budgeted hours (200 hours) were consumed, the AC would be 25% less than budget (\$22 000) but the EV would not indicate this. It would only show that the budgeted amount of hours is equal to the earned hours, and the task is going exactly according to plan. Even if the actual person performing the work required 25% more hours (as would reasonably be the case if the person is at a 25% reduced rate), the EV with hourly units of measure would indicate at the end of the task that it was at 0.75 (cost performance index) efficiency, when according to currency units of measure the task would be under budget and showing 1.06 efficiency (cost performance index). In summary, this example demonstrates a flaw that can be realized particularly when performing EVM on engineering work if hours are the units of measure.

Table 8 – Example of issues when using hours as EV units of measure.

Resource	Rate ($/h)	Actual Hours to complete the work	Total Cost
Original Person	150	200	$30,000
Actual Person Performing the Work	112.50	200	$22,000
Actual Person Performing the Work	112.50	250	$28,125

This research also proposed the use of currency as the units of measure for engineering work due to the forecasting component. Forecasting hours does not necessarily give the owner a transparent or intuitive picture of where the project is headed. As you get to higher levels of the WBS, forecasted hours do not directly translate to currency because the hour rate ($ / h) is not clear. It is a mixture of many different hourly rates.

A primary reason why hours would be a unit of measure is to avoid skewing of the EV when large material or equipment is purchased. However, this is not the case for engineering work as there are less equipment and material purchases that would influence or skew the EVM, as may be the case in construction.

3.3.2.2 Establish Progress Measurement for Management and Support Work-Packages

Management and support work involves the daily activities involved in project management and coordination, quality controls, risk management, project controls, or any other work that does not involve a clearly definable or unique deliverable and is considered an on-going activity, dependent on the progress of the actual design work. The deliverables for this type of work often include consulting services, meetings, workshop participation, but the clear deliverable is the complete design product.

A standard technique to measure management and support type work is either the Level of Effort approach suggested by GEIA (2007) where progress is awarded by the passage of time based on the planned level of effort for each time period, or alternately progress could be measured based on Apportioned Effort, recommended in the same document where progress of a supporting task is tied to the progress of the task that is being supported.

The issue with the first standard method (Level of Effort) is that effort is awarded incrementally due to the passage of time, yet if the time period for the activity extends or shortens, this approach does not account for this change. For example, if the activity Project Management planned to spent a uniform amount of effort over the course of a 10-month design project, it would receive 10% progress per month (100% / 12 months). In this way, after 5 months of the project, the Project Management task would be 50% complete; however, if the scheduled end date for the project was pushed back by 2 months, and assuming the Project Management task must continue until project completion, this task would realistically be only about 42% complete (5 months / 12 months).

The issue with the second standard approach (Apportioned Effort) is that if management effort were tied to progress of engineering phase design deliverables explicitly, this would result in skewing the progress high or low based on a good month or slow month, and therefore raise flags to look into management when this is actually not required. Progress of management is not so much tied to the period-to-period highs and lows of progress as management.

It is a service offered over time and will be performed whether good progress is being made on design or progress is slowed. Management effort is generally uniform over the course of design.

In this phase, management and support work progress is recommended to be measured using uniform distribution of effort from the start date of the work to latest estimated end date. Progress would be allocated based on this distribution through the passage of time using monthly increments. This progress would be updated each period based on the updated schedule according to the following formula:

$$P_i = \frac{100\%}{(LSED - SD) + 1} \times i \qquad \text{Equation 32}$$

Where:

P_i is the cumulative progress for period i

$LSED$ is the latest schedule end period for the package in question

SD is the start date for the package in question

i is the period number in question

The reasoning behind this is that management effort is generally uniform over the course of preliminary design but does not have well-defined deliverables. The assumption is made that progress will be awarded in uniform increments each period based on the latest number of periods for the project.

As a supplement to management progress, there are often workshops that require an increased effort on the management side. These workshops may be for design reviews, risk analysis, constructability reviews, value engineering, and etc.. Because these workshops are substantial and well-defined, progress for management effort can be supplemented with specific progress measurement for workshops completion. This is facilitated by management planning the amount of effort going towards the workshop and this effort being earned at completion of the workshop.

3.3.2.3 Establish Design Discipline Progress

The proposed methods to measure progress for design discipline work are split into three types:

- Preliminary design.
- Detailed design.
- Construction.

These have been chosen because they represent the different stages of engineering work in regards to work scope, type of work, and deliverables. For example, the work scope in the preliminary design phase is significantly less defined than in the detailed design stages such that preparing a list of clearly definable deliverables is often unrealistic at early stages of the project.

3.3.2.3.1 Preliminary Design Progress Measurement

In essence, the preliminary design is about answering the questions regarding the design so that once the preliminary design is complete, the design direction and deliverables are very clearly laid out. This means that preliminary design is far less focussed on the production of drawings than it is on the assessment of design options performing special studies and investigations, and reducing the uncertainty and unknowns in the design.

The progress measurement recommended for this work involves detailing out a list of the scope to be performed in each category for each design discipline and tracking progress based on milestones for these. The four categories are drawings, specifications, design reports, and special studies. The reasoning for this approach is in preliminary design there are less drawings and much more time spent performing special studies and investigations to determine the most optimal designs. Progress measurement must account for this.

Drawings in this case do not require developing the list of all individual drawings as this is typically not feasible at the start of preliminary design. Rather, the drawing list would be made up of drawing types (e.g. roads profile drawing type, roads section drawing type) and the relative amount of effort to go into each drawing. Specifications are detailed out into the individual specifications that would be required for each design discipline based on the project delivery method. Design reports would be initially listed at report level. For example, a structures design discipline may develop a list of design reports to be provided for each major structure on the project with relative level of effort for each report. Once the preliminary design progresses, these lists are detailed into the various chapters on the report and each chapter would be tracked separately. Special studies involve any significant studies to be undertaken by a design discipline that involve their own deliverable or require separate tracking apart from the other components of the design.

The relative amount of effort that would be allocated to each of the four categories would become the progress weighting for each category. As each category is detailed, the individual items within them are assigned a relative level of weight to facilitate progress measurement within each category.

Due to scope uncertainty in the preliminary design, it may be divided into several milestones, each milestone detailed out as it approaches. This means that the same is true for the progress. The four progress categories would be detailed out for each milestone separately as they arise.

The milestones used to measure progress for each category are according to the milestones discussed below.

For drawings and specifications, it may not be feasible to determine individual budget for each item; however, some drawings and specifications require significantly more effort than others. In order to avoid skewing the progress results due to this disparity in effort, each drawing and specification is assigned a weighting for the relative level of effort required. This is facilitated by assigning each drawing or specification to an effort category: low, nNormal, or high.

1. Low effort category: typically includes those drawings/specifications that are essentially duplications of another drawing/specification with only minor modifications. This category is assigned a weighting of 1.
2. Normal effort category: this accounts for drawings/specification that requires an average amount of effort to complete. This category is assigned a weighting of 3.

3. High effort category: this accounts for any unique drawings/specification developed with very little basis to build from compared to the normal drawings. This category is assigned a weighting of 5.

The normal category level is the default and low and high are used as needed to account for obvious discrepancies in effort between deliverables. Only three categories are used to in order to keep the process as efficient as possible without sacrificing accuracy. Weightings 1, 3, and 5 are used because they provide enough differentiation between the categories, but still allow each deliverable a significant contribution to the progress. If for example, weighting 1, 2, and 3 are used, the differentiation between the categories is not significant enough to warrant this approach; on the other hand, if 1, 5, and 10 weightings are used, the differentiation between low and high is more significant than the typical discrepancy between and high effort drawing or a low effort drawing.

Progress for each individual drawings or specifications is measured based on pre-set milestones defined below:

(1) Base work (a%): stablishing base plans and contract plans, acquiring information, and any preparatory work that must be completed before a drawing is officially started. This stage was developed to account for the less tangible work that occurs to facilitate drawing progress and to give a more accurate representation of progress at the beginning of a project.

(2) Started (b%): When work on a drawing has officially started.

(3) Progressing (c%): Work on a drawing is progressing toward first review. At times, drawings are started but are put off for a variety of reasons, where no progress is being made. In order to account for this

circumstance, a drawing enters the progress stage only when significant work has been completed on it.

(4) First design review submittal (d%): When a drawing is submitted for approval at the first review stage.

(5) Substantial progress (e%): Drawings that have been approved at 70%, comments are being incorporated, and drawing is progressing significantly toward final review submission.

(6) Final design review submittal (f%): When a 95% drawing is submitted for approval.

(7) Nearing Completion (g%): When a drawing is undergoing final modifications due to reviews and comments.

(8) Complete (100%): When a drawing is submitted for 100% approval and is ready for procurement.

As a default, the cumulative milestone weights are proposed to be: a= 5%, b=15%, c=40%, d=70%, e=80%, f=90%, g=95%. These milestone weightings have been refined after use in practice, but may need to be customized to the individual project at hand. When we compare these milestones to the recommended milestones weights in literature, there are some similarities and some large discrepancies. The following are discussed in literature:

Construction Industry Institute (1986) approach:

- Start drafting (0%).
- Drawn, not checked (20%).
- Complete for office check (35%).
- To owner for approval (70%).

- First issue (95%).
- Final issue (100%).

Eldin (1991) approach:

- Drawing started (title block complete) (5%).
- Issued for engineering review (50%).
- Checked and signed by engineer (70%).
- Checked and signed by PM (75%).
- Client comments incorporated (95%).
- Issued for bid/construction (100%).

Awarding 0% progress for starting the drawing, as suggested by CII, will tend to skew the EVA in the initial stages of the design pessimistically, and cause significant forecasted overruns. Having a minor milestone set to 5% (basework) accounts for the work that is inevitably occurring in the initial design stages, but is not directly translating in tangible drawing progress.

The next milestone (started) is not accounted for by Eldin. The gap between the first and second milestone in Eldin will lead to a gap in progress when the drawing is between started and issued for the first review. Adding an interim milestone such as “started” at 15% tends to smooth out the progress and provide a more consistent progress curve. CII only awards this second milestone after the draft drawing has been completed (but not checked). The effort to develop the initial drawing will likely take more effort than 20%.

Milestone 3, “progressing” is also not accounted for in Eldin, but is very similar to milestone 3 in CII. This milestone is recommended to capture the effort between a drawing being started and submitted for initial review.

Milestone 4, “first design review submittal” appears on both the literature approaches and all are at 70% to 75% cumulative weight.

Milestone 5, “substantial progress” is not necessarily captured in the literature suggestions, but is recommended to account for the time between design reviews. Typically, this time is substantial enough to warrant an interim milestone that indicates that work is progressing on incorporating comments from the initial review and the drawing is about half way to final review stage.

Milestone 6, “final design review” is captured in CII under the “first issue” milestone. CII gives 95% credit for this milestone, but there is not enough effort between this review and incorporating final comments and changes in the drawings. The suggestion is to give 90% credit to account for the effort between this review and the completed drawing.

Milestone 7, “nearing completion” is not captured in either CII or Eldin, but is recommended to account for the work between final review and 100% completion. The final completion of the drawings has a tendency to drag on over enough time to warrant this milestone. If this milestone is not used, there may be a lag in progress, where it flattens out and then spikes to completion at the end. This has a tendency to skew the EVM results in the later stages of the project, where considerable effort is being expended to finish up the design.

Milestone 8 is when the drawing is fully complete. All approaches agree with this milestone.

Progress is rolled-up to the design discipline level by multiplying the percent complete for each individual drawing or specification by its effort category number:

$$P = \frac{\sum(p_i \times w_i)}{\sum w_i} \qquad \text{Equation 33}$$

Where:

P is the total progress for the design discipline

p_i is the progress for the drawing or specification i

w_i is the effort weighting (effort category number 1,3, 5) of the drawing or specification i

It should be noted that drawings or specification can be added or subtracted from this list as needed and the weights of individual drawings and specifications need no adjustment.

Progress for design reports is similar to that used for drawings, except it is broken into the individual chapters, and instead of effort weights for the chapters of the report (as used for the drawings/specifications), actual budget effort is assigned to each. Actual budget effort is used because this is feasible to identify for design report chapters which typically have around five standard chapters (introduction and background, design assumptions and constraints, design options, recommendations, cost estimate). The milestones are modified slightly from those shown above because the report does not require the same review process. The suggested milestones are:

- Basework (5%).
- Started (15%).
- Progressing (40%).
- Initial draft complete (75%).
- Final draft complete (100%).

Special study progress is based on completion of the individual tasks involved in the study. A work-plan of tasks is developed for the study and each task is given a simple percent complete according to started/completed. These work-plans should be to the individual activity level for the study in order to allow the progress measurement enough detail to accurately quantify where the study is at in each control period.

3.3.2.3.2 Detailed Design Progress Measurement

The same process can be used to measure progress in the detailed design as suggested for preliminary design; however, to increase efficiency of the system it can be simplified. Progress for detailed design work is more straight forward than preliminary design work. The management and support progress is no different than preliminary design (refer to the previous section for this information), but progress for design disciplines is more suited to simply measuring drawing and specification progress as these are where the primary effort is placed. There are much less special studies or design reports in detailed design than in preliminary design and almost all work in detailed design is linked to completion of drawings and specifications.

In this phase, design progress for design disciplines is based on a list of individual drawings and specifications with effort weights for each and milestone-based tracking. The list is put together at the outset of the design. All drawings and specifications to be completed are identified on a list for each design discipline.

3.3.2.3.3 Construction Progress Measurement

Engineering work during construction, with its intrinsic link to actual construction progress, requires a different approach to progress measurement than in design. The work that progresses during this phase can be split into three types:

- Management and support progress.
- Procurement progress.
- Construction progress.

Management and Support Progress

Management and support, as discussed previously, involves consulting services such as cost control, risk management, contract administration and document control, meetings, etc.. Progress for this work is proposed to be measured using one of three techniques:

- Uniform distribution of effort from the start date of the work to latest estimated end date, as suggested for preliminary and detailed design.
- Direct apportioning to construction progress such that management and support progress is only as far complete as construction is progressed. For example, if complete. This technique is beneficial for its ease of use and is suitable for situations where the level of effort required by management is directly related to where construction is at. The added benefit with this technique is that to sole focus for both the engineer and

the constructor is to gain construction progress, the engineer only receives credit for progress as construction progresses.

- Non-direct apportioning to construction progress based on relationship between management planned progress and construction planned progress. Management effort can have the tendency to be less uniform during the construction phase than it is during design. This requires management progress to be taken one step further. Progress is awarded based on the correlation between planned progress and overall construction progress. The management effort required per period will be planned out and this will be tied to the planned construction progress. If 10% of management effort was planned to be expended by the time 5% of construction progress was awarded, than management progress would be 10% complete at this stage. This technique allows for a non-uniform relationship between management progress and construction progress instead of the direct proportions that would be used in typical apportioned progress measurement. The technique here would be to plot the planned progress for the management or support task in question against the related construction progress as planned. The equation that represents this relationship can then be used to calculate the engineer's management progress for any progress increment during construction.

3.3.2.3.4 Design Discipline (Engineer of Record) Progress

EOR work involves the bulk of the engineering effort during construction. This work involves site monitoring, inspection, guidance, coordination, contract administration for both construction work and procurement. The approach used to measure progress for this work is based on the premise that progress of the

EOR is directly tied to progress of construction work. The second factor in developing this approach is the ease of implementation and use. The approach contains three components: General Participation and Support Progress, Procurement Progress, and Construction Progress. Incorporating each of these into components with appropriate weights allows for a robust measurement system for work that otherwise is very difficult to monitor. The procurement and construction progress is awarded based on establishing the relationship between engineering team progress and construction progress.

EOR General Participation and Support Progress

General Participation and Support (GPS) progress includes general work related to responding to Requests For Information (RFI`s), issuing Site Instructions (SI), filling out Notice of Proposed Changes (NPC`s), Change Orders (CO`s) which does not have a defined scope (you never know how many RFI, SI will be required) and being on-call for construction. This component involves 10% to 20% of total progress distributed evenly over the planned monitoring schedule (from start of procurement on related subcontracts, material, and equipment to end of post-construction phase). Weighting will be based on length of schedule and discipline.

For GPS progress to be earned, the monitoring team must complete all work in a high-quality and timely manner. This includes responses to Requests for information, Site Instructions, Notices of Potential Change, Change Orders, etc., as well as daily and weekly monitoring, reports, and meetings. At the end of the month the engineer’s management team will evaluate the performance of each EOR team in terms of quality and timeliness of work. This evaluation will determine the percent of the possible progress credit that will be earned in the month. For example, if a monitoring team is required to respond to five Requests For Information in the month yet only completed work for three of them on time and the remaining RFI's are critical to the construction progress they would not earn full progress.

The rating is between "0" and "3" as follows:

- A rating of “0” means that the EOR team has been none responsive and is delaying construction progress.
- A rating of "1" means the EOR team has severely underperformed in the month and is delaying construction progress --> Receives 25% GPS credit
- A rating of "2" means the EOR team has not satisfactorily completed some portions of their work during the month and this has the potential to delay construction. -->Receives 75% GPSP credit
- A rating of "3" means that the EOR team has performed all tasks satisfactorily during the month --> Receives 100% GPSP credit.

An example of the form that could be used for this work is provided in **Table 9**.

Table 9 – Sample General Participation and Support Progress Evaluation

EOR Team Monthly Progress Evaluation		
EOR Team	**Monthly Progress Rating (0-3)**	**Comments/Reasoning (if less than 3)**
Communications		
Buildings		
Track		
ROW Electrical		
TP/OCS		
Roads		
Drainage		

Landscape		
Heavy Civil/Structural		
Utilities		
Commissioning		

EOR Procurement Progress

Procurement Progress involves 0% to 20% progress earned through completion of the related procurement items (related subcontract packages and equipment procurement). To facilitate this, a list of all related subcontract, material, and equipment procurement that is to occur is developed and progress is tracked for these based on the procurement milestones shown in **Tables 10 and 11**.

Table 10 – Subcontract Procurement Milestones

Milestone	Weighting
Start Review of drawings and Specifications	1%
Review Substantially Progressed	15%
Scope Definition Complete	35%
Issue Request For Qualification	50%
Award Request For Qualification	55%
Issue Tender	60%
Close Tender	75%
Award Tender	95%
Proponent Mobilizing	100%

Table 11 – Material and Equipment Procurement Milestones

Milestone	Weighting
Identify procurement component	5%
Review Start	5%
Review Progressing	5%
Procure	10%
Award	10%
Manufacturing in Progress	15%
Manufacturing Complete	25%
Pre-Inspection	5%
Arrival	5%
Final Inspection	5%
Acceptance	10%

EOR Construction Progress

Construction Progress involves construction monitoring related work for site monitoring, quality and site inspections, and assurance that construction meets design intent. Here, 60% to 90% progress earned based on related construction work-package progress. This approach is based on the premise that an appropriate progress measurement system is also implemented for the construction work. Progress for construction work must be measured in an accurate fashion using the same periods as that used to perform EVM on the engineering work. An example of an appropriate milestone based progress measurement approach for construction work is provided in **Table 12** for a roadworks project.

Table 12 – Sample progress milestones for a roadworks project

Milestone	**Weighting**
Site Preparation	5%
Removals	20%
Excavation	15%
Sub-base	15%
Asphalt	20%
Surface	20%
Sidewalks	5%

The weighting for these three components of the EOR progress is suggested to be established based on a calibration technique using the PVs for the EOR team at the 25%, 50%, and 75% construction completion points of the related construction components. Based on the construction schedule the established progress measurement approach for construction, one can determine where the construction and procurement work related to an EOR team should be at the

25%, 50%, and 75% completion points. Based on this information, the weightings for General Participation, Procurement, and Construction can be set to match that planned construction progress. This technique allows for the progress measurement to be as closely matching the construction progress as practicable. It allows for customizing the progress measurement approach to the different engineering disciplines to match their expected level of effort.

3.3.2.3.5 Record Drawing Progress

The third type of work for engineer's in construction is Record Drawings completion. This involves the drawings that are kept for construction records and signed off by the EOR. Record Drawings is a task during construction that can be tracked separately from construction progress as these are the deliverables that will be provided to the owner at the end of construction. Similar to the approach used in the design phase, progress for Record Drawings is based tracking drawing progress according to a set of milestones. However, because this work no longer comprises the bulk of the engineer's work (as it does in design), there is less justification to track each drawing individually. The proposed approach is therefore to track Record Drawing completion based on design discipline using the drawing milestones shown in **Table 13**.

Table 13 – Record Drawing Milestones

Milestone	**Weighting**
As-built (red-line) drawings received or Construction Complete for drawing in question	*10%*
Record Drawings Started	*60%*
Record Drawing Complete	*30%*

These weights provide a suitable level of effort between the various steps and are a good default to use. It is recommended that these weights be customized to the project at hand by knowledgeable project manager's.

3.3.2.4 Incorporating changes into progress measurement

In the design phase changes that impact progress measurement can occur to engineering work by adding additional scope to a new control account or revising scope to an existing control account. If the ladder occurs, the progress measurement system must add the deliverable(s) (drawing, specification, or special study) associated with the change.

If a change to the design schedule changes the end date than a subsequent update to the management progress calculation must occur.

Changes to the construction work that is being monitored, inspected, managed by the engineer must be translated to the progress measurement for the engineering team. As discussed previously, the engineer's progress is linked to progress on the related construction work-packages. If an additional work-packages is added to the project, then the engineering progress measurement needs to add this work-package to the calculation. If there are changes to the scheduled end date of the project, the progress for management related work must be updated.

3.3.3 Summary Discussion

Progress measurement is a key process in EVM. This topic has been discussed extensively in literature and some techniques are offered in relation to engineering work. Despite this, there are still challenges with this topic that have to overcome. The proposed solution offered in this section has created a framework for measuring progress that both builds on existing literature and proposes new techniques that further the body of knowledge in the area and address the challenges with progress on engineering work. A discussion of how the key challenges have been addressed in this proposed approach is provided below.

C4. Establishing practical methods for measuring progress that encapsulates the entire engineering effort

Solution offered:

- A progress measurement approach for the complete engineering effort in design**,** including: an improved progress measurement technique for management and other continuous type work; a deliverable weighting system to account for differing effort on one drawing versus the next without actually having to allocate specific budget effort to each drawing. The past approach for measuring design phase work focussed on drawing and specification deliverables only but did not measure progress on management or other supporting work.

C5. Planning engineering work and measuring progress during the construction phase

Solution offered:

- A progress measurement technique for tracking engineering work in construction that is integrated with construction and procurement progress and accounts for the effort that an engineering team must intrinsically dedicate resources to even if progress on site is not occurring.

No approach is offered in the reviewed literature for measuring engineering work during construction. Engineering work is difficult to measure during construction because there is a lack of clear deliverables that dictate progress. The approach is integrated with the baseline development approach discussed above, thus creating an integrated technique for controlling engineering work based on related construction work.

- A calibration technique to determine progress weighting for the different components of Design Discipline/EOR work during construction (general participation, procurement, and construction components of progress). Different disciplines require slightly different levels of effort for construction, procurement, and general participation. For example, a roadworks engineering discipline would likely require less effort in procurement than a communications engineering discipline would because there is significant amount of individual and specialized equipment required for communications work during construction. This technique projects the construction progress and then sets the engineer's progress weights so that progress will match the PVs as much as possible.

The next section addressed the process of allocating and compiling AC for engineering work.

3.4 Actual Costs

Actual cost in EVM refers to the invoicing, allocating costs, and estimating processes involved in determining how much has actually been spent and where has it been spent. This is an important component of EVM application and generally does not involve a great deal of complexity. The purpose of including this chapter is to cover the few areas involved in actual costs tracking that can drastically impact the effectiveness of the proposed system for controlling engineering work. Figure 19 depicts the necessary components of collecting and allocating actual costs as they relate to engineering work.

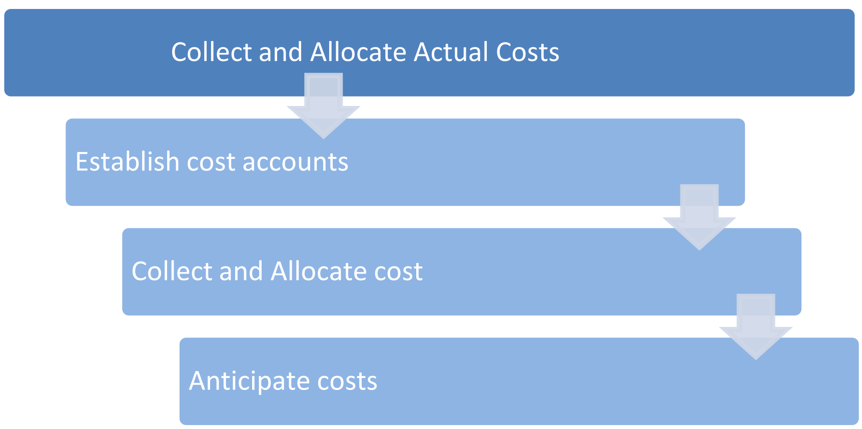

Figure 19 – Requirements of collecting and allocation actual costs for engineering work.

3.4.1 Challenges with Implementing on Engineering Work

There are several important issues that have been identified in the area of actual costs tracking for EVM. The key challenge that is addressed in this section is:

- C6. Correctly allocating actual costs congruent with progress.
- C9. Gathering the required information to perform EVM in an accurate, efficient and timely manner.

These fall into three sub-topics, namely:

a) Establishing cost accounts to optimum level of detail.
b) Mischarging of cost.
c) Invoicing cycles not matching EVM cycles.

These are summarized as follows:

a) **Establishing cost accounts to optimum level of detail:** The first major hurdle related to capturing actual costs for engineering work is related to establishing cost accounts (or cost accounts for the purposes of accounting). These accounts, as mentioned in **Section 3.1,** must be matched with the project WBS to allow the schedule and cost to be integrated. That being said, the development of the WBS must account for the constraints of cost reporting and allocating in order to allow for meaningful and efficient cost allocation. In construction, cost accounts are detailed to a very finite level of detail to reflect the material and type of construction work. It is easier to define cost accounts in construction because the work is often more easily differentiated. Engineering work on the other hand is plagued with overlaps and interrelationships that make it difficult and often cumbersome to allocate cost to the same level of detail. In addition, allocating engineering work to a finite level of detail is also often not meaningful enough to warrant the added effort. With that in mind, a balance point needs to be reached when establishing cost accounts. They must be detailed enough to allow for meaningful differentiation of cost between the components of the engineering work and they must also be coarse enough to facilitate proper charging by both internal employees and external allocation of sub-consultant invoices.

b) **Mischarging of cost:** Once the proper accounts are established for controlling cost, it is still not a given that costs will naturally be charged where they are supposed to. Currently there does not seem to be enough emphasis on correct charging for engineering work and this reduces a project controls system to an accounting tool to catch mischarging, not a forward looking project management tool to control the cost and schedule performance. If charges are not going to the account that they are budget in, the project controls system will be showing inaccurate performance and information. It may be showing an overrun in one account due to incorrect charging to this account, and an underrun in another because the expected costs have not been allocated properly.

This issue applies to both internal charging within a company as well as allocation of external sub-consultant invoices into the cost system. At times, this issue is driven by the lack of formal communication of where to charge or delay of communicating this information to the project team. In an engineering project, there are two forms of cost accounting that take place: the individual firm or firms accounting system(s), and the project accounting system. The project accounting system is where the control accounts are established and the formal project controls system is implemented. The individual engineering firms accounting system is the established system used within the engineering firm for all their internal accounting purposes. It is this internal accounting system that produces the invoices. It is therefore crucial that this internal accounting system for the individual accounting firms matches the project accounting system. If this is not the case and the cost accounts that show on the invoices do not transfer easily into the project accounting structure, there will invariably be mischarging of costs to incorrect accounts. For a project controls system to be effectively implemented on engineering work, a method to ensure costs are allocated to the correct accounts must be established.

c) **Invoicing cycles not matching EVM cycles**: In construction, invoicing is generally very consistent and timely. Cash-flow for construction project is critical to the construction companies involved and is there is generally a project specific invoicing cycle. A significantly late invoice in construction would be rare. For engineering work, one would think that this is same; however, it is the experience of the author that the billing cycles between different engineering companies can vary in timing and late invoicing is more common than in construction. This creates challenges for implementing a project controls system on engineering work. If invoices are received late or not at all for a given reporting period, the earned value analysis would show an optimistic view of the project. Progress would be earned in the period but costs would not be reported, falsely indicating a higher performance. If the billing cycle for an individual firm does not match the reporting cycle of the project, the progress reporting cycle would not match the actual cost cycle and therefore always be skewed one way or the other. An example of mismatching invoicing and reporting cycles is if a consulting company invoices on a four week cycle and the EVM is on a monthly cycle. The matching of progress cycles to actual costs reporting must be accounted for in the system.

3.4.2 Proposed Solution

In order to implement an effective project controls system for engineering work the process for accumulating and allocating actual costs must not be overlooked.

As mentioned above there are various issues specific to engineering work that necessitate a customized solution.

3.4.2.1 Establish Cost Accounts

When establishing the cost accounts one should take into account the division between the management and support and design disciplines, the components of these disciplines, and the design firms involved on the project. For engineering work, the goal is have cost accounts directly match the EVM control accounts. As shown in **Section 3.1,** setting up control accounts is proposed to be at level 2 (design discipline level). Consequently, cost accounts developed at this level is the ideal situation. However, when multiple design firms are involved in a project, this breakdown into design components may require further division. Dividing between the firms involved on the project simplifies the allocation of costs and the assignment of responsibility for a control account. If more than one firm has budget in the same control account it can be difficult to pinpoint where performance is deviating from the plan and where the actual cost are originating. The recommended approach is depicted in **Figure 20 and 21**. Essentially, if a design component (control accounts) contains more than one design firm, it is recommended to separate these into separate control accounts.

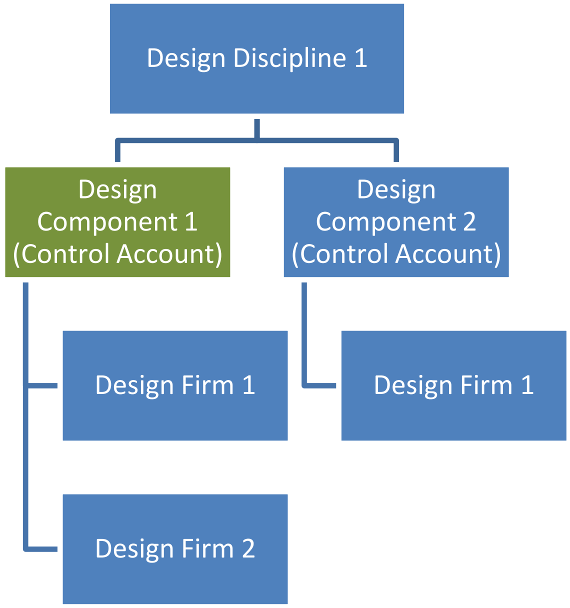

Figure 20 - Control account with two design firms charging to same account.

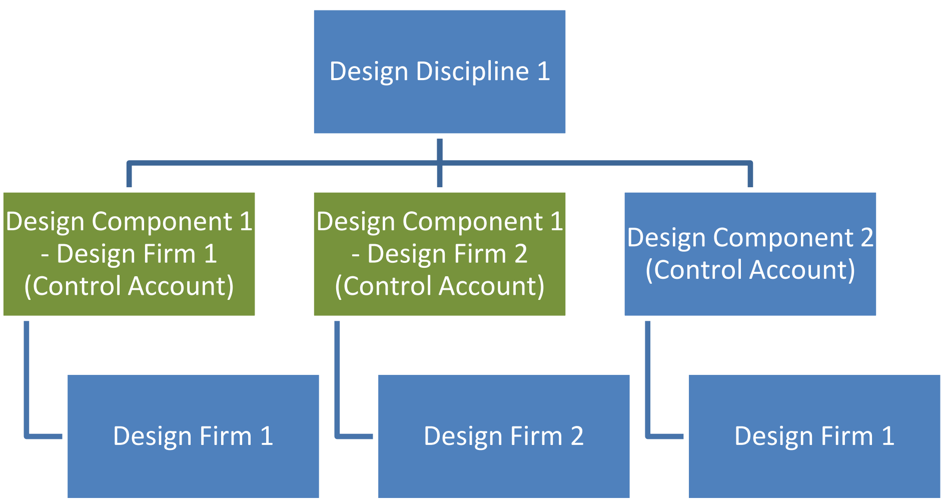

Figure 21 - Division of control account to separate between design firms for cost accounting.

The WBS being structured by design discipline makes coding of time and costs simpler and more reliable. Often for engineering work, the individual engineers and other resources charge their time to the accounting system themselves. Unless they are given explicit direction of where to charge time (and in some cases even if they are given this explicit direction), they will charge their time to the area on the accounting system that is labeled with their discipline. If the accounting structure is not setup to account for this and design disciplines are mixed, the chances of mischarging are greatly increased. Well delineated control accounts for individual disciplines improve accuracy of charging as well as reduce overhead cost of management having to sort through and reallocate time.

At times, design components may be better divided by geographic regions of the design to help reduce uncertainty with where time should be charged. It is intuitive for engineering staff to allocate design effort to geographic regions of a design. For example, a designer doing a roads design for various different street and avenues within the project could easily allocate their time to the specific road that they were working on. This should be assessed on a case-by-case basis for the project at hand.

3.4.2.2 Collect and Allocate cost

Once the cost accounts are established, collecting and allocating costs to the proper accounts becomes the focus. The technique offered to alleviate mis-charging within a company is to create a charging protocol. This protocol would specify where actual costs should be charged for each group, person, and firm on the project. The key to success of this protocol is its communication to all project team members at the beginning of the project, before individual firm accounting systems are established for the project. If all accounting firms can match their invoicing structure to the project control accounts, a large problem is solved with allocating costs. In most cases it is recommended that the external firms must have costs broken down into control accounts that they are assigned.

3.4.2.3 Anticipate Costs

The challenge of late or mismatched billing cycles is recommended to be handled by using an estimate of effort for each project reporting cycle. This estimate of effort would ideally be generated by the individual firm in the absence of an official invoice. It would detail the cost of work performed within the project reporting period, regardless of invoicing cycle and would be more than just an estimate, but rather pulled directly off the firm's accounting system for the desired time period. In a worst case scenario, where the firm has not delivered an invoice or an estimate of costs, the costs for the time period in question can be estimated by either of the following depending on the situation:

- Use the planned expenditure for the period in question multiplied by the cumulative cost performance.
- Taking the average burn rate of all prior periods.
- Using the planned budget expenditure for the period in question from the EVM baseline.
- Using an estimate of effort based on management opinion of the likely accrued costs.

The first option is considered to be the method most in-line with the proposed EVM approach in this document. It takes into account the past performance in anticipating the actual costs for the next period.

3.4.3 Summary Discussion

The topic of AC related to EVM on engineering work contains unique challenges that must be overcome. To revert back to the 10 key challenges, the key challenges that are addressed in this section are:

C6. Correctly allocating AC that are congruent with progress

Solution Offered:

- Structuring the WBS based on design discipline to reduce errors in charging by internal staff.
- Recommendation for modifying WBS control accounts to allow division between different engineering firms on the project. This facilitates more accurate control. If a control account contains more than one firm, pin pointing which firms is contributing poor performance may be difficult and cumbersome.
- Proposal to use a charging protocol document that lays out very clearly which person or firm is to charge to which account.

C9. Gathering the required information to perform EVM in an accurate, efficient and timely manner

Solution Offered:

- A technique to estimate AC in the absence of invoicing that is customized to engineering work was developed to help ensure that costs are always up-to-date with progress. This solves the issue evident in engineering work where invoicing at times does not match the progress measurement timing (e.g. late invoicing is much more common in consulting).

3.5 Performance, Forecasting, and Corrective Action

The previous sections have dealt with how to develop and facilitate EVM, this next section gets to the heart of the matter, the actual earned value analysis (EVA). It discusses how the planned value, earned value, and actual costs are put together and used to determine performance, analyze trends, forecasts end results, and correct poor performance. The process steps involved in this section are provided in **Figure 22**.

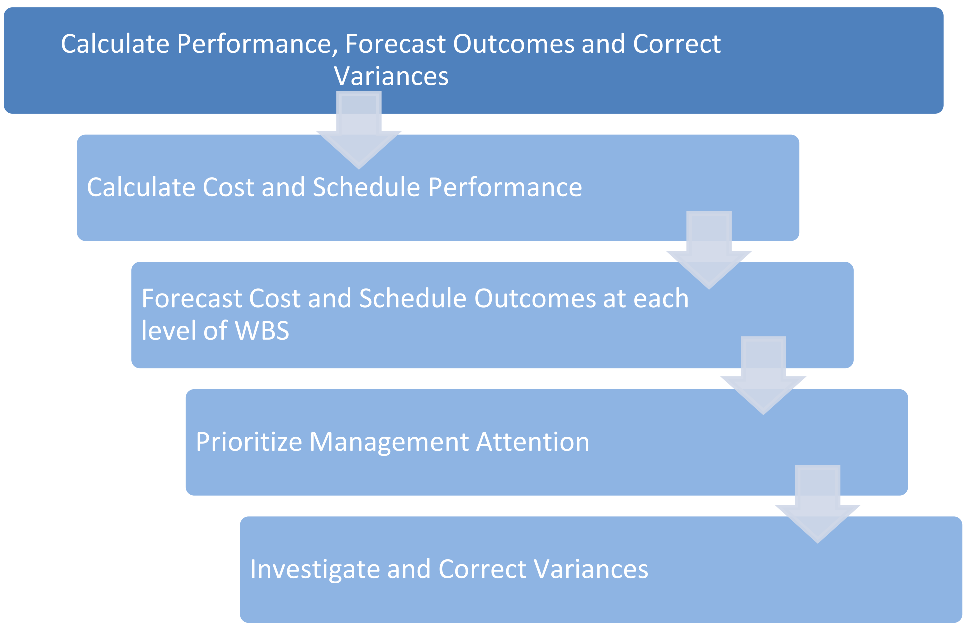

Figure 22 – Requirements for calculating performance, forecasting, and correcting.

3.5.1 Challenges with Implementing on Engineering Work

There are several important aspects of this section that are particularly important to address if EVM is to be successfully applied to engineering work.

- C7. Prioritizing corrective actions for performance variances.
- C8. Forecasting that accounts for the relationship between cost and schedule unique to engineering work in design and construction phases.

The specifics of which include:

a) Schedule performance measurement

b) Forecasting to account for schedule performance

c) Rolling-up Forecast

d) Prioritization of management attention

e) Forecast reliability

The following provides an explanation for each of these.

a) **Schedule performance measurement:** EVM schedule performance measurement has undergone much scrutiny as discussed in the literature review in the previous section. Although schedule performance in design is far less complex than construction, schedule performance is of particular importance in design due to its link to cost.

b) **Forecasting to account for schedule performance:** The forecasted cost at completion for engineering work is highly dependent on the schedule. This is because engineering work is nearly always paid at an hourly rate basis. The longer the engineer is working the higher the cost. The author explains that cost and schedule are highly interdependent in the design phase (Chang A. S., 2002). Stating that “reasons for cost increase are also normally the reason for time increase” (P. 30, Chang, 2002). This is because the increased work takes time to accomplish and/or the increased time takes funds to accomplish. A tight schedule would require more effort and additional costs. For this reason it is particularly important to include schedule performance in the forecasting methodology for engineering work.

   During construction, the engineer’s work is highly dependent on construction performance and this is a contributing factor in the forecasted cost for the engineering work. If a construction project was 5 months over schedule, the engineering team would likely be involved on the project for an additional 5 months, undoubtedly with additional expenses. Again, this suggests that schedule performance may play a role forecasting for engineering work.

The question is to what degree does schedule performance impact the forecast? Generally, only overhead or continuous type work is highly subject to schedule performance. For example, project management type work is required continuously over the duration of a project and so cost is dependent on schedule performance. Other types of work that are more directly linked to progress and relatively discontinuous, are less subject to schedule performance for forecasting costs. For example, the engineer of record for an electrical portion of a building project who is required on-site at certain intervals for inspection would be much less dependent on schedule performance for cost forecasting. They would be on-site when required and then allocated to other projects when not required.

In design, engineers are generally assigned full-time or near full time status to complete the design. The flow of work in design is much more in the engineer's control and is generally steady over time. If the design where delayed, perhaps due to decision delays or other reasons, the design team would generally be kept on the project and not re-allocated to other work. This means that during the design phase costs are directly linked to schedule. In construction, however, the work is more discontinuous and requires less of an engineer's effort. The engineer's effort during construction is directly proportional to the work occurring on-site and the engineer is often not allocated to the work on a full-time basis. Usually only a minimal percentage of the engineer's time is allocated to any one construction project. This means that if the work is slow or delayed on the construction site, the engineer would allocate their time to other projects. This phenomenon leads to a different forecasting technique for engineering work during construction. A technique that is less dependent on schedule performance or not dependent on it at all.

c) **Rolling-up Forecast:** Forecasting can be undertaken using two approaches. One technique is rolling up the earned value, actual costs and planned values of all individual accounts at the lowest level of control (control accounts) and then performing the EV calculations at the rolled up level. The second technique is to calculate all EV indices at the control account level calculating the forecasted cost at completion at this level and then rolling up the individual forecasts to the project level. These two approaches give different forecasting results. The first technique has a tendency to provide more optimistic results than the second technique and the second technique is a more accurate and intuitive approach. The issue with the second approach is that there tends to be a discrepancy between the rolled-up performance indices (CPI and SPI) and the forecast at completion. It can very often be the case that the summarized CPI and SPI are above 1.0 and the forecast at completion is showing an overrun. The following tables (**Table 14 and 15)** demonstrate the two approaches and the different results that they yield.

Table 14 – Traditional technique for rolling up forecast to the project level.

Task	BAC	AC	% Complete	EV	CPI	EAC	VAC
A	$ 100	$ 100	100%	$ 100	1	$ 100	$ -
B	$ 200	$ 100	40%	$ 80	0.8	$ 250	-$ 50
C	$ 300	$ 100	30%	$ 90	0.9	$ 333	-$ 33
D	$ 400	$ 100	15%	$ 60	0.6	$ 667	-$ 267
E	$ 500	$ 100	50%	$ 250	2.5	$ 200	$ 300
Total	**$ 1,500**	**$ 500**	**39%**	**$ 580**	**1.16**	**$ 1,293**	**$ 207**

In the traditional approach the EV is rolled up from the individual tasks to the project level to give $580 earned value. This is then used to calculate the total progress, CPI, EAC, and VAC. The resulting calculations show that the project is performing well in terms of cost and is projecting a budget under run of $207.

Now observe the alternate approach suggested by Lester (2006) and Eldin N.N. (1991) shown in Table 9. This approach sums the EAC and VAC from the individual task to the project level. The first thing that is observed is that the VAC is now very different than that calculated using the traditional approach. It forecasts a $50 budget overrun, a very different conclusion than from the traditional calculation.

Table 15 – Example of alternative approach to rolling up forecast to project level.

Task	BAC	AC	% Complete	EV	CPI	EAC	VAC

A	$ 100	$ 100	100%	$ 100	1	$ 100	$ -
B	$ 200	$ 100	40%	$ 80	0.8	$ 250	-$ 50
C	$ 300	$ 100	30%	$ 90	0.9	$ 333	-$ 33
D	$ 400	$ 100	15%	$ 60	0.6	$ 667	-$ 267
E	$ 500	$ 100	50%	$ 250	2.5	$ 200	$ 300
Total	**$ 1,500**	**$ 500**	**39%**	**$ 580**	**1.16**	**$ 1,550**	**-$ 50**

It should be noted, that the project level % Complete, EV, and CPI do not correlate with the forecast in the second approach. In this example, the CPI indicates it is at 1.16, but the forecast is showing that the CPI should actually be below 1.

d) **Prioritization of management attention:** A critical factor in an efficient and successful project controls system is the accurate prioritization of management attention on the areas of highest concern. Typical EVM provides cost performance indices that let management know where task stands in terms of cost and schedule, but it does not define thresholds for when and what kind of management attention is required. For example, if a task had a CPI of 0.95 during the second month of a 24-month project, does project management need to act immediately in rectify the discrepancy? What level of cost or schedule performance warrants concern from the owner? Which task is of higher priority to rectify at task performing a CPI of 0.5 with a budget of $25 000 or a task performance at a CPI of 0.8 and a budget of $100 000? The project controls system needs to produce prioritized results that easily guide management attention to correct the critical areas and not worrying about the less important areas.

e) **Forecast reliability:** A primary feature of EVM is the ability to provide forecast of the final cost and schedule of a project in order to give a good indication of where things are headed. The difficulty with this is the reliability of the forecast. The forecasts are a very effective way of prioritizing where management attention is required, but with the current EVM techniques these forecasts can only be treated as indicators. The forecasts are subject to wide swings from period to period as cost and schedule performance change. At what point and to what extent can the management team rely on the forecast that is being calculated?

3.5.2 Proposed Solution

The proposed approach to performing EVM analysis and forecasting is built on the basics of EVM discussed in this research and customizes these for implementation on engineering work.

3.5.2.1 Calculate Cost and Schedule Performance

In EVM, performance is related to both cost and schedule. The proposed approach uses the traditional cost performance index (CPI) calculated using the formula:

$$CPI = \frac{EV}{AC} \qquad \text{Equation 34}$$

For schedule performance on the other hand the recommended approach uses the technique suggested by Vanhoucke (2009) originally from Lipke (2003. This method utilizes an earned schedule metric that is calculated by mapping the earned value at any point in time to the corresponding planned value, thereby finding the time that the earned value should have been realized according to the baseline plan values.

$$Find\ t\ such\ that\ EV\ \geq PV_t\ and\ EV\ < PV_{t+1}$$

$$ES = t + \frac{EV - PV_t}{PV_{t+1} - PV_t} \qquad \text{Equation 35}$$

Where:

ES	Earned Schedule
EV	Earned Value at the actual time
PV_t	Planned Value at time instance t

The schedule performance is then calculated by dividing the ES by Actual Time (AT) lapsed. AT is measured in terms of periods (e.g. if 6 periods have passed than AT is 6).

These indices are calculated for both the individual periods and as cumulative indices. This allows for management to see how performance progressed in the individual period without diluting that performance with the cumulative indices. Both values give an important indication of performance.

3.5.2.2 Forecast Cost and Schedule Outcomes at Each Level of WBS

Forecasting for engineering work, with its dependency on both cost and schedule performance requires an approach that includes both of these indices. However, different types of engineering work require different relationship with schedule performance for forecasting costs. The recommended techniques for forecasting offered in this section are customised to the different types of work. In general, the equation provided below is used as the starting point for all forecasting methods discussed.

$$EAC = AC + \frac{BAC - EV}{FPI} \qquad \text{Equation 36}$$

Where:

FPI is the Forecasted Performance Index

FPI in this case can take on any appropriate value based on both cost and schedule. Several combinations are relevant:

$$FPI = 1.0 \qquad \text{Equation 37}$$

$$FPI = CPI_{cumulative} \qquad \text{Equation 38}$$

$$FPI = CPI_{cumulative} \times SPI_{cumulative} \qquad \text{Equation 39}$$

$$FPI = CPI_{3\ period\ average} \times SPI_{3\ period\ average} \qquad \text{Equation 40}$$

$$FPI = (\propto \% + CPI_{cumulative}) \times (\propto \% + SPI_{cumulative}) \qquad \text{Equation 41}$$

$$FPI = A(CPI_{cumulative}) + B(SPI_{cumulative}) \qquad \text{Equation 42}$$

$$FPI = A(CPI_{3to6\,period\,average}) + B(SPI_{3to6\,period\,average}) \qquad \text{Equation 43}$$

Where:

A and B are the weight of the CPI and SPI from (0 to 100%) which sum to unity

$\propto$ % is the expected change to the respective performance index-based expert opinion

These equations are recommended to be used at different times throughout the projects life and are applicable to different types of engineering work.

As discussed in **Section 3.5.1** regarding schedule performance in the forecasting equation, the relationship that cost of engineering work has with schedule performance is different between the design phase and construction phase. Therefore, the forecasting techniques recommended in this research are divided into design phase forecasting and construction phase forecasting.

3.5.2.2.1 Design Phase Forecasting Approach

Costs for design work have a direct proportion to schedule performance. For this reason, the combined cost and schedule formulae are used for all types of work during the design phase. Which of these formulas to use during the design phase is dependent on the stage of the project.

For this purpose forecasting for each control account is divided into three segments: first stage (start to 25% complete), mid stage (25% to 75% complete), and final stage (75% to 100% complete).

At the beginning of the project, the performance indices are relatively unstable. This is due to three reasons: one is that the cumulative indices have not yet had enough periods to make them stable. The more periods that are used to average a performance index the more stable it becomes. The second reason is the sensitivity of the forecasting equation to variances at the beginning of the project. Because the forecasting equation extents past performance onto the remaining work, when the remaining work heavy out-weighs the completed work, the impact of past performance can skew the forecast significantly. The third reason is progress measurement error (percent complete error). Measuring progress is not an exact science. If a progress measurement technique inherently had a plus/minus error of two percentage points, then at the beginning of the project, when progress is 5% complete for example, this 2% error could change the forecast at completion drastically.

For the first stage, and adapted from the suggestions by Kerridge (1986), the future performance (FPI) is set at 1.0 for this stage. Kerridge (1986) suggested that this formula be used until the project is 50% complete, but this approach will reduce the impact and effectiveness of the forecasting in the early stages when decisions can have the greatest impact. Using this formula in the first stage allows time for the project to stabilize and creates more reliable forecasting results. It is the author's experience that using the cumulative indices for forecasting at the early stages of a project creates unreliable forecasts that fluctuate widely from period to period. This forecasting can have the tendency to decrease the project teams buy-in to the forecasting approach and make them less likely to take the forecasting seriously in later portions of the project.

As the project progresses into the mid-stages and amount of work is accelerating, the forecasting generally becomes more stable. However, with the acceleration of work occurring at this time, the cumulative indices are not always the best representation of future performance. At times, the average of the latest periods may be more effective as a forecasting tool.

For the mid-stage, and adapted from Nasser (2005), the future performance index should be based on 3 to 6 period averages depending of management input and the status of the task in question. As a default, the 6 period average should be used as it will be the most stable, but is still free of the unstable performance indices in the initial reporting periods.

The final stage should be based on the cumulative index that is modified by the expected change in the respective performance as the project nears completion. This formula allows for management input and expert opinion to be included in the forecasting in the final stages of the project. In these final stages, management generally has a good handle on the expectations for future work and any corrections that will be made to correct performance. This subjective performance correction approach is derived from Alshaibani (1999).

3.5.2.2.2 Construction Phase Forecasting Approach

As mentioned previously, forecasting for engineering work during construction requires a different approach than design. The cost of engineering work is not influenced by the schedule performance to the same degree as design work. Engineering work during the construction phase is separated between continuous work and discontinuous work. Continuous work is likened to management type work or work where the personnel are allocated to the job at a full or near full-time basis and are required on the job regardless of construction progress. Generally for construction work this would be the project manager or management team. Discontinuous work includes the work required by a design discipline/engineer of record or inspectors that are tasked with periodic work tied to the construction progress.

For continuous work, the recommended approach is to use a proportioned combination of cost and schedule performance according to the equation:

$$FPI = A(CPI_{cumulative}) + B(SPI_{cumulative}) \qquad \text{Equation 44}$$

Where:

A = 80% as a default; and B = 20% as a default

This proportion is suggested because it accounts for the construction progress, but is not heavily skewed by it. The reason to reduce the link to schedule performance is that construction work (especially non-critical activities) are subject to excessive changes during construction and this skews the engineer's forecast. Another reason to reduce the link to construction schedule is that this relationship is also accounted for in the management progress measurement approach suggested in **Section 3.3.2**, that is linked to construction schedule.

For discontinuous work (design discipline/EOR), the recommended forecast is simply:

$$FPI = CPI_{cumulative} \qquad \text{Equation 45}$$

The link to schedule performance is very low in this case because the engineering effort is on an as-needed basis and follows construction progress. The progress measurement approach in this case addresses all schedule linkage and is therefore accounted for in the forecast through the cost performance index.

3.5.2.2.3 Rolling-up the Forecast to Higher Levels of WBS

The forecasting discussed above is for the control account level on the WBS. Often it is more effective and meaningful to show the forecasts at the higher levels of the WBS and/or the project level. As discussed, there are several approaches used in literature to do this. One involves rolling-up or summing the earned value of all lower level accounts that feed into a higher level account and then calculating the performance indices and forecast at this level. The second approach is summing the individual forecasts for all lower level activities and rolling-up these values to the higher level WBS account. This research proposes the second approach for forecasting because it is a more realistic approach. The reasoning for this conclusion is that it is at the lower WBS level, the control account, that progress is being measured and budgets planned; therefore, this is this level that forecasts would be most accurate. Consequently, a summation of the lower level forecasts would constitute a more realistic forecast for the higher levels of the WBS.

A hurdle to overcome with this suggested approach is that the forecast using the sum of lower level forecasts creates a discrepancy at the higher level WBS accounts between the forecast and the % Complete and CPI (**as shown in Section 3.5.1**). The suggested technique to avoid this discrepancy is to back-calculate the EVM indices using the forecast. In this way, the progress would be calculated using the actual costs to date divided by the forecast at completion.

$$\%\,Complete = \frac{AC}{EAC} \qquad \text{Equation 46}$$

From this percent complete, the forecast based earned value and subsequent indices can be calculated.

3.5.2.3 Prioritize Management Attention

Knowing when and to what extent the forecast calculated using the EVM approach can be relied upon is important to project managers and owners. For project managers this can useful in prioritizing corrective actions, and for owners it can be used to determine where additional expenditures are imminent, where savings can be expected, and where they cannot yet be relied on. This research proposes the use of Forecast Criticality Index (FCI) to determine the reliability and significance of a forecast. Performance indices trends and consistency of those trends as well as the potential impact that the forecast could have on the project are used to determine criticality of forecast. This approach also accounts for expert opinion in the calculation to allow for increased effectiveness of the outcomes. The input of experience project managers and experts in the field is a very important in components of project controls systems. For a project controls system to be accurate, reliable, and consistent, it must be able to accommodate expert opinion and input in calculations (Nasser, 2005).

The FCI is calculated using the formula:

$$FCI = aC + bS + cM \qquad \text{Equation 47}$$

Where: a, b, c are weights for each component as determined by the project team with a default of a=25%, b=25%, c=50%

C is the consistency of the Performance

S is the significance of the forecast

M is the Management Opinion of the project management team

The following tables (Tables 16,17,18) provide the details of each of the FCI component.

Table 16 – Components of the Forecast Criticality Index.

Weight	**FCI Component**	**Description of calculation**
25%	Consistency of forecast (C)	Take performance factor status over last five periods of project and count the number of times the current performance factor status has appeared in the latest five periods. Divide this by five periods to get the value.
25%	Significance of forecast (S)	Divide the forecasted amount by the total project amount. Select the significance category that the weighting fits into using Significance Category Table (**Table 17**). Take Significance value from the corresponding table.
50%	Management opinion (M)	Management team selects a descriptor between 1 and 5 representing their impression of the future performance of the task in questions using the Future Performance Table (**Table 18**). Then, take the corresponding value from the table.

Table 17 - Significance Category Table.

Weight Range	Value to use
0 to 0.5%	0.14
0.5 to 1%	0.29
1 to 2%	0.43
2 to 4%	0.57
4% to 8%	0.71
8% to 15%	0.86

15% and up	1.00

Table 18 – Future Performance Table with list of Descriptors for selection by management.

Rating	Descriptor	Value to use
1	No concern, investigation reveals that it will be brought back on track.	0.2
2	Slight concern, there is some reason to think that the task will not rectify.	0.4
3	Somewhat concerned with the results of investigation into task. There are some meaningful indications that the task will under-perform.	0.6
4	Significantly concerned with the task overrunning. Responsible party in charge of task is indicating significant concern outside of their control.	0.8
5	Very high chance of maintaining the current or worse trend to end of project.	1

By using this index the project team can better focus attention on the most critical components of the project. Because forecasting is a highly subjective and coarse look into the future it is important to develop a means of increasing the project team's confidence with the forecasting results. Much research is underway to increase the effectiveness of forecasting; however, a simpler look into the consistency, severity, and "gut feel" of the calculated forecasts has the ability to improve the usefulness of any forecasting method.

3.5.2.3.1 Status Indicators

A critical factor in a proper project controls system is that it effectively directs management attention to the areas of concern and prioritizes that concern. A technique to accomplish this proposed in this research is color-coded status indicators. Cost and schedule performance are easily represented by the EVM indices CPI and SPI, respectively. If we can group these indices into categories that distinguish the seriousness of the performance for each component of the project being controlled, we can better prioritize management attention. The proposed Status Indicators are divided into four categories: Green, Yellow, Red, and Black (Microsoft Corporation, 2012). **Table 19** provides the descriptions of each of these categories. These Descriptions also provide the severity of corrective action that is suggested.

Table 19 – Status Indicator categories and descriptions and suggested corrective actions.

	Cost	Schedule
GREEN = On track or better	Cost is on budget or under budget for the work completed to date. No attention required.	Task is on or ahead of schedule. No attention required.
YELLOW = Slightly behind schedule or over budget	Cost is slightly over budget for the work done to date. This may be due to discrepancies in progress measurement, lower productivity than expected, some incorrect charging (cost billed to wrong account), etc. and attention into this task is recommended to be performed over the next few periods.	Schedule is slightly over budget for the work done to-date. This may be due to discrepancies in progress measurement, lower productivity than expected, small delay in start date, etc. and this task should be observed over the next few periods to determine if the current trend continues.
RED = Needs immediate attention	Cost is significantly over budget for the work performed to date. This task requires investigation to determine the cause(s) of the poor performance and to determine corrective actions. Observe trend closely over next few periods.	Schedule is significantly over budget for the work performed to date. This task requires investigation to determine the cause(s) of the poor performance and to determine corrective actions. Observe trend closely over next few periods.

BLACK = Critical/needs review of item and plan	Very poor cost performance. Detailed investigation into this task is required immediately and corrective action to be implemented as soon as possible. This task must be managed very closely until performance improves or task is stopped.	Very poor schedule performance compared to the baseline. Detailed investigation into this task is required immediately and corrective action is to be implemented as soon as possible. This task must be managed very closely until performance improves, baseline is updated to reflect the revised schedule of this task or task is stopped. Candidate for baseline revision

The status indicators are set by assigning performance index ranges (CPI, SPI ranges). These ranges can be set at static value or the ranges can be dynamic over the course of the project. This research proposed dynamic ranges to be used. The reasoning for this is that dynamic can be set to larger values at the beginning of the project when the performance indices are still unstable and fluctuating dramatically from period to period and can be progressively narrowed as the project progresses. This increases the effectiveness of the project controls system in directing management attention to the areas of actual concern and weeding out the items that may be falsely showing poor performance. This false poor performance can typically arise at the beginning of the project due to discrepancies in progress measurement or other components as well as unstable cumulative indices. As the project moves on, the indices and progress become more stable and accurate and as this occurs the status indicators can be tightened to better catch under performance. Table 20 contains the recommended ranges for each status indicator over the life of the project.

Table 20 – Dynamic Status Indicator Ranges.

	First 3 Periods	First Quarter	Second Quarter	3rd Quarter	Final Quarter
GREEN	0.9 and up	0.95 and above	1 and above	1 and above	1 and above
YELLOW	0.7 to 0.9	0.75 to 0.95	0.8 to 1	0.85 to 1	0.9 to 1
RED	0.4 to 0.7	0.5 to 0.75	0.5 to 0.8	0.6 to 0.85	0.7 to 0.9
BLACK	less than 0.4	less than 0.5	less than 0.5	less than 0.6	less than 0.7

3.5.2.4 Investigate and Correct Variances

Using the status indicator approach to EVM analysis described above, it is the status indicators that drive corrective action in a structured and methodical way. Each period, the EVM indices are calculated and the status indicators are assigned. Based on these status indicators the project controls group on the project is tasked with communicating this status to each of the parties responsible for a given WBS control account. The status indictor would also indicate when a response is required from the responsible party and how in-depth that response needs to be.

For example, if a control account was assigned a red status indicator for cost performance, the party responsible for that account would then be required to investigate any rationale for why this status is red and determine a plan of action moving forward to rectify the trend. If the responsible party indicates that the performance cannot be improved than this information feeds into the Forecast Criticality Index and the resulting impact to the final cost of the project is communicated to the owner and the project team for further corrective action development.

As you will see in the next section, this corrective action is reported in line with the earned value analysis results to provide a complete picture of the project when the EVM is presented to the owner.

3.5.3 Summary Discussion

This section dealt with the earned value analysis calculations, forecasting and corrective actions. Many of the techniques offered in the section are adaptations of techniques offered in literature. The approach combines techniques from various sources to design a system that can be used to increase the effectiveness of EVM in general. In order to link back to the objectives of this research, the following provides a summary of the key challenges that are addressed in this section.

C7. Prioritizing corrective actions for performance variances

Solution offered:

- A technique for determining the criticality of forecasts at any level of the WBS with inclusion of management input, consistency of the forecast, and severity of the forecast in relation to project outcomes. Often forecasts are unreliable and fluctuate wildly from period to period. The techniques proposed allow the management team to determine which forecasts must be addressed and which are less critical.
- Use of dynamic status indicators for determining corrective action thresholds and focussing management attention. These color coded status indicators allow for larger variances at the beginning of the project

and gradually close-in as the project progresses. This approach is linked to a system for determining severity of performance variances and triggering differing levels of action from the project team. This adds significantly to the efficiency of the project controls system.

C8. Forecasting that accounts for the relationship between cost and schedule unique to engineering work in design and construction phases

- Dynamic forecasting approach based on stages of the project. The research draws from a vast field of research related to forecasting using EVM and combines various approaches to create a dynamic forecasting system using different forecasting equations at different stages of the project cycle. The approach provides recommendations for forecasting using schedule performance as a contributing factor.
- Proposed approach for forecasting at the project level as a sum of the individual forecasts. This is a contribution that addresses the tendency for the traditional form of forecasting at the project level to give overly optimistic results when based on rolled-up progress, not rolled up forecasts. This research purports that summing of individual forecasts at the lowest level (control account level) to get the project level forecast (or forecast at higher levels of the WBS) is a more accurate technique. This technique also demonstrates that the traditional form of progress roll-up to the project level based on weighted averages potentially gives a false percent complete when compare to the forecast based percent complete (actual costs to-date divided by forecasted costs at completion).
- A forecasting approach that is unique to engineering effort during construction. The engineering effort during construction is highly

dependent on the construction progress and should be linked to this for forecasting. The difficulty is that construction work (especially none critical activities) are subject to excessive changes during construction and this skews the engineer`s forecast. The proposed approach discusses how this link to construction schedule is accounted for in the progress measurement and forecasting for engineering work during construction.

The last of final section of the proposed approach deals with the reporting of the EVM results.

3.6 Reporting and Decision Making

The final step in EVM is reporting the results. This involves reporting to various levels of management from control account managers, project management, and owners, each with their own desired level of detail. **Figure 23** depicts the various components involved in this section.

Figure 23 – Overview of the components involved in reporting EVM results and making key project decisions

3.6.1 Challenges with Implementing on Engineering Work

The key challenges that remain to be addressed are:

- C9.Gathering the required information to perform EVM in an accurate, efficient and timely manner
- C10. Reporting results visually and effectively to various levels of detail

These can be broken down further into:

a) Frequency of reporting

b) Visualization of reporting

c) Different reporting level requirements

d) Early identifying and documenting of potential budget under run and overruns

a) **Frequency of reporting**: The frequency of reporting project controls results is proven to have an impact on the success of the system, the tighter the timeline for reporting the more effective the controls. This is balances by the need to have reasonable and manageable timelines for invoicing and reporting progress. In construction, there is seldom a problem with receiving timely invoices, whereas engineering work has less defined timelines. Generally invoices are issued on a monthly basis, but at times this is not received at the beginning of the following month. For EVA results to be reported in a timely manner, the timeline for invoices is required as early in the month as possible.

b) Visualization of reporting: EVA requires extensive calculation and produces a plethora of useful information. The problem is reporting this information in the most effective way. Although there are traditional figures used in EVM that shows trend and planned budgets, there is often more information than can be communicated in a figure. Not to be disregarded is the fallback of "over-information," that is providing so much information that the meaning is lost in the "sea of numbers." For this reason it is desirable to have as visual a reporting approach as possible using more than the traditional figures or tables.

c) **Different reporting level requirements:** Reporting anything on a project whether it be project controls related or not always has to keep in mind the audience that is being reported to. The required level of detail is different for a senior manager or owner than it is for the individual engineers responsible for a control account. The senior manager or owner is typically interested in the project level results such as overall cost and schedule performance and the forecast at completion; whereas the engineer is more interested in the progress measurement calculations and what the resulting performance is for their individual control account. For this reason, EVA reporting needs to be flexible. It needs to provide reports at various levels of the WBS and include different levels of detail. An effective project controls system must have this capability to gain the respect of the project team.

d) **Early identifying and documenting of potential budget under run and overruns:** Engineering work is different than construction work in that less emphasis is placed on the identification and documentation of potential budget overruns and underruns. In construction it is customary to have a formal change management system outlined in the contract documents whereby the constructor is obligated to identify and document any potential changes to the work that would lead to increased (or decreased) costs or durations. This lack of transparency and structure in engineering work can be detrimental to the both the owner and the engineering firm. Without early identification and exposure of potential overruns, the owner could be surprised toward the end of the project with a request for more money from the engineering firm when they realize that they will not have enough budget to finish the job. Consequently, the engineering firm, without having properly documented the potential overrun, may find it difficult to claim to the owner for the extra costs. As can be seen, there is merit in creating transparent and periodic budget and progress tracking to allow for early identification and documentation of potential cost and schedule deviations.

3.6.2 Proposed Solution

3.6.2.1 Determine Timing of Reporting

The timelines for this reporting is recommended to be monthly. This is due to the fact that most engineering and consulting companies follow a monthly invoicing schedule and therefore the smallest reasonable period for meaningful EVA analysis would be one month. It is the experience of the author that these timelines must be very well defined and this is especially the case on larger more complex projects where more than one engineering company is involved in the project. In order to report on the most current EVA results, a proposed timeline for monthly reporting is provided below as a recommendation (**Table 21**). This timelines has proven to allow enough time for a variety of invoicing schedules and layout the various tasks that should be undertaken for consistent and effective EVA reporting to the owner.

Table 21 – Recommended reporting timeline

Reporting Task	Due date
Invoices from all firms submitted to prime consultant	10^{th} of the month
Invoices coded and compiled by prime consultant and issued for EVA	13^{th} of the month
Preliminary EVA compiled and reported to engineering team for comment and corrective action	16^{th} of the month
Engineering team meeting to review EVA and discuss	18^{th} of the month
Final EVA compiled and reported to owner	19^{th} of the month

Meeting to review EVA with owner and upper management	21st of the month

It is important that the timeline for reporting is a tight as feasible for the project size and scale. It is the experience of the author that monthly reporting is not unrealistic for even large and complex design projects of over $30M budgets. The longer the timeline between reporting and the wider the gap between what is being reported and the actual reporting date, the less effective and meaningful the EVA results.

3.6.2.2 Produce Reports to Various Levels of Detail

The key to reporting EVM information is to have a dynamic and visual reporting approach that can be customized to any level of detail depending on the audience. If the intended audience is high-level management or the owner, the required information would be the project level results – overall cost performance, schedule performance, the forecasts at completion and an overall trend figure. If the intended audience is a party responsible for an individual control account than the required information would be much more detailed, including the specific progress measurement calculations and individual trend graphs for the control account only.

The proposed approach is built off of the WBS-based project controls system that is discussed throughout this document. The WBS allows the EVA information to be reported at any level of the WBS. The primary reporting is a combination of four components: a “Dash-board” Report, an EVA Figure, a Performance Indices Figure, and a write-up and explanation of the results.

The Dash-board Report contains all the relevant EVA information for the desired level of the WBS. A sample of this report is provided in **Figure 24**. As can be seen, the report contains a variety of information but can be split into different components. The first columns show the percent progressed, percent spent, and percent planned to be spent. This provides rather intuitive and immediate feedback on where the item currently sits. The next columns provide total budget, total spent to date and expenses in the latest period. This information provides an immediate look at how much money has been spent and what the burn rate was in the last period. Moving further left on the report, the EVA cost and schedule variances and indices are provided both cumulatively and for the period. The next section provides a look at the forecasted cost and variance at completion. Typically the most noteworthy section of the report, the forecast, provides the anticipated end result and impact to the project. The last three columns of the report contain the status indicators and the comments column. The comments column allows for inclusion of important notes and summary of investigation into poor performance and corrective action. Several features of the report add the visual feedback including the arrow trends and budget size indicators. The arrow trends indicate the direction of performance from the last period to the present. An upward arrow indicates performance is improving, a downward arrow that performance is decreasing and a flat line indicates that performance has been consistent. The budget size indicators provide immediate feedback on which accounts contain the largest budgets and are therefore the most significant and important to monitor. All in all, this report allows for at-a-glance status updates and prioritization of management attention.

Task Name	Progress	Budget Spend	Planned Progress	BAC	Total Actual Cost	Period Actual Cost	CV	SV	CPI Per.	CPI Cumu.	SPI Per.	SPI Cumu.	FCAC	CVAC	Cost Status	Sched. Status
1000.01 Project Management	35.6%	33.6%	36.3%			$170.776	$154.616	-$57.248	1.17	1.06	1.30	0.98		$189.676		
1000.02 Project Controls	29.4%	32.1%	32.3%			$78.694	-$103.912	-$112.841	1.26	0.92	0.97	0.91		-$382.517		
1000.03 Management Support	20.8%	27.8%	25.7%			$42,871	-$149,291	-$104,489	0.68	0.75	0.78	0.81		-$668,334		
1000.04 Technical Support	17.3%	14.0%	15.9%			$14.438	$19.585	$8.297	3.64	1.24	3.86	1.09		$62.189		
1000.05 Construction Mgr - RFP	100.0%	100.0%	100.0%			$0	$0	$0	0.00	1.00	0.00	1.00		$0		
1000.06 Design Modifications	82.0%	70.7%	77.5%			$86,758	$416,931	$166,833	-4.71	1.16	-15.10	1.06		$508,453		
1000.07 Other Con. Contracts	100.0%	95.9%	100.0%			$0	$13,087	$0	0.00	1.04	0.00	1.00		$13,087		
1000.08 Procurement Packaging	85.0%	58.8%	100.0%			$0	$113.898	-$65.381	0.00	1.45	0.00	0.85		$134.053		
1000.10 Buildings	22.7%	16.7%	17.2%			$8.564	$36.111	$33.113	2.69	1.36	1.42	1.32		$159.247		
1000.11 Commissioning	21.7%	25.2%	27.5%			$42,505	-$92,042	-$154,298	0.84	0.86	0.68	0.79		-$424,721		
1000.12 Communication System	28.3%	32.1%	42.4%			-$19,243	-$31,549	-$116,206	0.00	0.88	1.81	0.67		-$111,070		
1000.13 Drainage	56.3%	67.3%	35.9%			$15.415	-$34.689	$63.769	0.45	0.84	0.00	1.57		-$61.822		
1000.14 Environmental	63.4%	63.4%	58.0%			$0	$0	$13.414	0.00	1.00	0.00	1.09		$0		
1000.15 Geotechnical	7.4%	7.4%	35.0%			$0	$0	-$55.289	0.00	1.00	0.00	0.21		$0		
1000.16 Heavy Civil	28.7%	46.9%	34.0%			$158,811	-$364,728	-$106,367	0.27	0.61	0.39	0.84		-$1,268,294		
1000.17 Landscape	8.5%	5.7%	3.4%			$170	$6,395	$11,593	8.42	1.49	0.00	2.50		$74,171		
1000.18 Roads	58.1%	22.8%	29.1%			$2,234	$267,250	$219,831	2.88	2.55	0.00	2.00		$460,305		
1000.19 ROW Electrical	24.5%	30.1%	37.8%			$3,143	-$10,479	-$25,037	0.74	0.81	0.25	0.65		-$42,807		
1000.21 Signals - CBTC	34.0%	46.0%	20.3%			$75.457	-$212.426	$243.535	0.47	0.74	0.89	1.68		-$624.782		
1000.23 Survey	100.0%	105.7%	85.9%			$4.087	-$2.648	$6.571	0.00	0.95	0.00	1.16		-$2.648		
1000.24 Trackwork	19.7%	29.6%	15.1%			$35.773	-$80.416	$37.300	0.13	0.67	0.48	1.30		-$407.618		
1000.25 Traction Power	13.8%	26.4%	19.4%			$39,779	-$83,347	-$37,497	0.22	0.52	0.42	0.71		-$604,712		

Figure 24 – EVA Table (not that comments column normally appears as the left most column but has been removed due to sensitive material).

The next component, the EVA Figure, builds off of the traditional EVA figure with the cumulative PV line along with the AC and EV lines plotted as the periods progress. This figure also shows the approved budget and the forecasted cost at completion of the project. This is a useful figure in seeing the trends from period to period. A sample of this figure provided below in **Figure 25.**

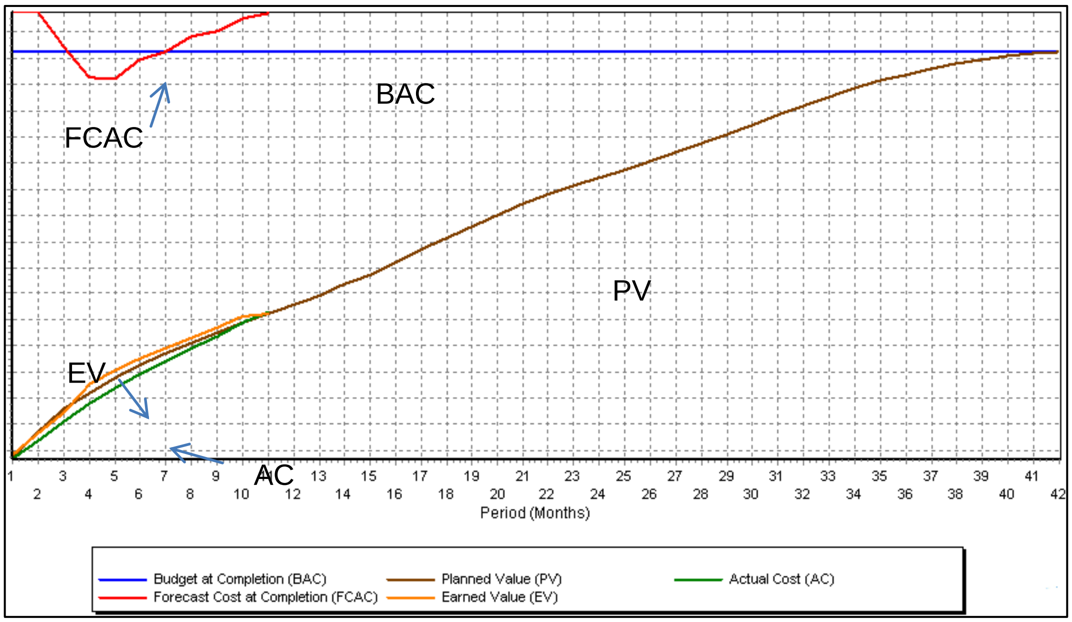

Figure 25- EVA Figure

The third component of the reporting is the Performance Indices Figure (**Figure 26**) which depicts the cumulative cost and schedule performance indices against the "Ideal" performance index of 1.0. This figure exposes how the project starts off with highly fluctuating performance, but as the project progresses the trends stabilize and give a good indication of where the project is headed.

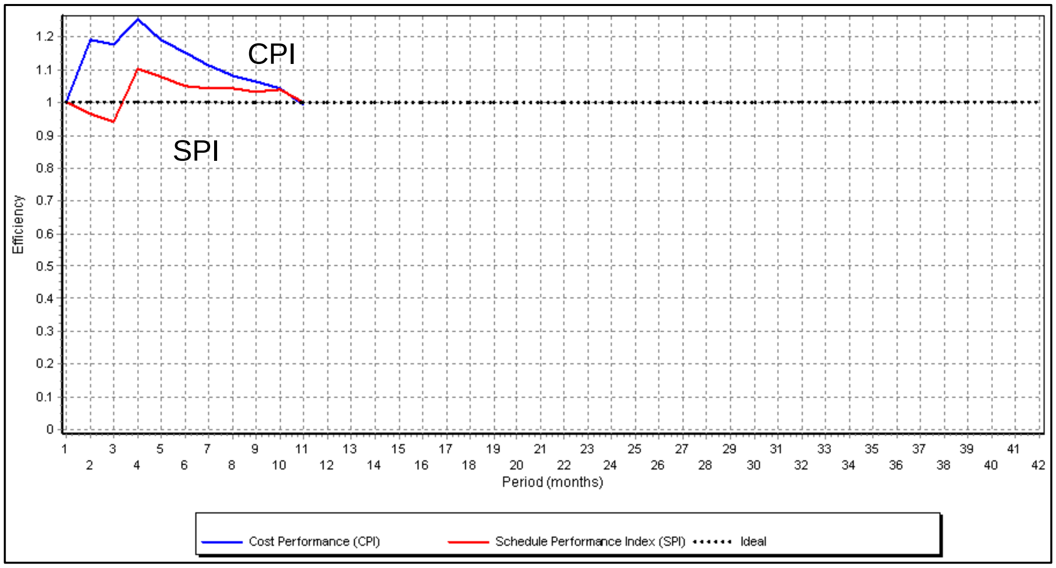

Figure 26 – Performance Indices

The final component of the standard report includes a write-up that summarizes and describes the EVA results and the subsequent tables and figures contained therein.

These reports are compiled every period over the life of the project and submitted to the owner for review. Each period a progress meeting would be held to review the EVA and discuss the results and corrective actions.

3.6.2.3 Meet to Review Reports

A key to effective reporting is to tie face-to-face meetings with the project team and owner into this reporting process. The recommended approach is to schedule and hold a meeting for each reporting period of the project, because the proposed project controls approach described in this document is geared toward creating transparency of the project status for the owner and management team. Two meetings are recommended to be held. One meeting to review the EVA results with the engineering project team before they are finalized and issued to the owner, and the next to review with the owner and upper project management. This allows time for the engineering project team to know what is being reported to the owner and prepare to answer the questions that may arise.

3.6.2.4 Make Project Level Decisions

Reporting such as that described in the previous section creates a level of transparency that allows owners to be aware of budgets and performance at individual account levels of the WBS instead of simply the project level. This may seem undesirable to some engineering firms because it has the potential to remove the flexibility that the engineering team has with internal budgets and expenditures. However, it has the benefit of allowing the client due warning and justification for internal budget shifts and re-allocations. This is done through the monthly reporting, status indicter process, and allows for proper documentation and substantiation of budget overrun and under runs before they happen. In the end, this transparency will act in favor of the engineering team as the owner is far more willing to issue a budget change for an overrun that was identified in advance and attempted to be rectified than one that is brought to the owners attention after the project has finished. Furthermore, the EVA process allows for properly substantiated overruns and under runs because the scope for a given control account must be clearly defined for the budget and progress measurement to be developed. With this, it is easily seen when there is an activity that is outside the scope, and in any case this would be documented on a monthly basis through the reporting process.

The budget under and overrun indicated through the EVA process also helps the project team to see not only where budgets have a risk of overrun budget, but also the potential areas to draw from to fund the overruns. For example, if in a design project the structures design was showing significant risk of overrun, but the roads design was showing an underrun to a similar extent, the project management could re-allocate budget from roads to structures without having to ask for a change order from the owner.

By exposing both the overruns and under runs, there is increased potential for added value to the owner. If a project is continually showing a budget savings at the end of the project for the current scope, it may be desirable by the owner to add additional scope to the work to improve the final product. This could include additional quality checks, review workshops, additional design components, and etc. This is also beneficial to the engineering team because the better managed the owner's expectations, the higher the potential for future work on other projects.

3.6.3 Summary Discussion

The final key challenges with implementing EVM on engineering work are addressed in this section. A summary of how each was addressed is provided in the following.

C9.Gathering the required information to perform EVM in an accurate, efficient and timely manner

Solution offered:

- A proven timeline to be used for monthly EVM including all required steps from invoicing and reporting progress, to preliminary results distribution and investigation, to corrective action development and reporting and finally to meeting and decision making.

- A proven timeline to be used for monthly EVM including all required steps from invoicing and reporting progress, to preliminary results distribution and investigation, to corrective action development, reporting, and finally to meeting and decision making. This is especially an issue on major engineering projects where multiple consultants and sub-consultants have to feed into the EVM system. Literature does not touch on this.

C10. Reporting results visually and effectively to various levels of detail

Solution offered:

- A structured approach to reporting performance and determining corrective actions for engineering work in design and construction phases that leads to transparency with cost and schedule status.
- Highly visual system for reporting performance not only using the traditional figures but also adding color coded status indicators, color coded trending arrows, and budget size indictors on the summary EVA table. This provides at-a-glance EVA information at any level of detail and contributes to the efficiency of the recommended system.
- A technique for producing reports at differing levels of details as required, that builds off of existing literature and customizes to the engineering effort.

4 APPLICATION OF PROPOSED APPROACH

The project controls approach offered in this thesis is intended to improve cost and schedule control of engineering work. This next section is used as both proof that the approach works and to demonstrate specific techniques that have been used to implement this form of project controls in practise.

The North Light Rail Transit (NLRT) Detailed Design was used as the initial test with implementing the EVM techniques to design phase project controls. The EVM techniques were applied parallel to the existing project controls (e.g. schedule and accounting summary) on the project to test its merit. From this application, it was proven that the project controls approach was effective for controlling engineering work in the design phase. Numerous improvements were taken from this application and used to refine the project controls approach discussed in this research. With the success of this first application, the owner requested that the approach be extended to controlling engineering work during the construction phase. The NLRT construction phase was conducted with the benefit of the lessons learned from the initial application, but also exposed the fact the controlling engineering work during the construction phase requires different techniques than those used for design work (e.g. progress measurement and forecasting calculations).

Some of the details in these applications (e.g. individual budgets) have been removed due to the sensitivities with this information and the firms involved in the projects.

4.1 North LRT Detailed Design

4.1.1 Background

The North LRT (NLRT) line extends from the existing LRT system in Edmonton's downtown core to the Northern Alberta Institute of Technology 3.3 kilometers to the north. From initial concept planning in 2007 to the present, the NLRT has progressed through various stages of planning and design including: concept design, where alignments and overall designs for the line were selected; preliminary design, where alignments were finalized and 30% designs were completed; and detailed design, where the final designs were completed and prepared for construction. It is this detailed design stage that is the focus of the project controls case study in this document.

LRT projects are complex, require major financial investments, and are high-profile projects, and for these reasons they benefit greatly from comprehensive project controls.

Unlike other construction projects such as building a road or storm tunnel, LRT projects involve a large multidisciplinary team. These teams are comprised of planners, designers, managers, and experts in many facets of construction including: roads, drainage, landscape, structural, architectural, communications and signal systems, train power systems, track, tunneling, noise and vibration analysis, operations and maintenance organizations, and utility companies, to name few. Generally, this kind of expertise is not found in one single company, but rather each area is a specialty of its own. This results in the involvement of many different organizations in one project. On the NLRT, over 12 different organizations and 12 different disciplines were involved in the detailed design phase alone. This created the need for integrated and well-structured cost and schedule control during the detailed design.

LRT projects are also costly projects that are funded by various levels of government and taxpayer dollars. The North LRT project in Edmonton averaged roughly $250 Million in total project budget per kilometer of LRT (City of Edmonton, 2011). Even in the design phase, they are expensive projects; the NLRT consumed over $20 Million over a year and a half. Because of this expensive draw on taxpayer dollars, the need for transparent and accurate cost control is paramount, even during design.

These projects can also create major disruption for the transportation routes of the City. At times, this type of work can require complete closure of major traffic arteries or shut-down of existing LRT operations. These sorts of disruptions require extensive planning and coordination of schedules and if timelines are not met, the entire project can be delayed or cancelled. It is for this reason that schedule control on LRT projects is also of utmost importance.

Past LRT projects in Edmonton have implemented more common forms of project controls, whereby costs were tracked and reported on a quarterly basis, but were not directly compared to actual progress. Schedules were reported more regularly, but there was no form of structured progress measurement or detailed integration with cost management. This increased the risk of cost and schedule overruns to the city and inspired the need for improved forms of project controls.

For the reasons described above, and in order to better manage the risk of cost and schedule overrun, the proposed EVM approach was applied parallel to the traditional forms of project controls currently being undertaken on the project.

The main goals of the system were to (1) forecast final project costs and duration on a monthly basis, and (2) monitor cost and schedule performance at a detailed level on a monthly basis to allow for timely correction.

4.1.2 Applications

4.1.2.1 Baseline

From the outset, the EVM approach was restricted to the existing structure (WBS), schedule and budgets that were already in-place. This inhibited use of some of the baseline development techniques that are proposed.

In order to implement the EVM two key components were required: (1) Integrated cost and schedule work breakdown structure (WBS), and (2) structured progress measurement techniques. The integrated WBS was created at the outset of the project to a level of detail that would facilitate the EVM approach and assignment of responsible parties to each package. An example of this WBS is provided in **Table 22** below:

- Baseline developed to disciplines, but not to design components
- Distribution of budget over schedule was uniform for all control accounts

Table 22 - Sample Integrated WBS to second level with cost, schedule, and responsible parties (content is for illustration purposes only)

Top Task	Sub Task - Level 1	Task Name	Schedule		Original Budget			Responsibility
			Start	End	Budget ($)	Person Hrs	Deliverable	
1000		**Project Management**	**14-Sep-09**	**3-Dec-10**	**1,000**	**1,000**	**Apportioned to Design Progress**	
	1001	Project Coordination	14-Sep-09	7-Dec-10	1,000	1,000		John
	1002	Project Overview	14-Sep-09	7-Dec-10	1,000	1,000		John
	1004	Project Management	14-Sep-09	7-Dec-10	1,000	1,000		John
1100		**Project Controls**	**22-Sep-09**	**3-Dec-10**	**1,000**	**1,000**	**Apportioned to Design Progress**	
	1101	Document Control & Comm	14-Sep-09	7-Dec-10	1,000	1,000		Jane
	1102	Project Cost Control & Repo	14-Sep-09	7-Dec-10	1,000	1,000		Ray
	1103	Project Scheduling	14-Sep-09	7-Dec-10	1,000	1,000		Jim
1200		**Quality Management /**	**24-Sep-09**	**22-Oct-10**	**1,000**	**1,000**		
	1201	QA	14-Sep-09	7-Dec-10	1,000	1,000	reports	Bob
	1202	Review Workshops	14-Sep-09	7-Dec-10	1,000	1,000	workshops	John
1300		**Management Support**	**21-Sep-09**	**7-Dec-10**	**1,000**	**1,000**		
	1301	CADD Support	22-Sep-09	7-Dec-10	1,000	1,000	Drawings	Kyle
	1302	Contract Reviews	21-Sep-09	7-Dec-10	1,000	1,000	Subjective	Roger
1400		**Design Support Services**	**14-Sep-09**	**7-Dec-10**	**1,000**	**1,000**		
	1401	Building Condition Surveys	1-Jan-10	4-Dec-10	1,000	1,000	Schedule	Fred
	1402	CPTED Review	5-Oct-10	5-Oct-10	1,000	1,000	Schedule	Mark
	1403	Crossing Protection	14-Sep-09	4-Dec-10	1,000	1,000	Schedule	Jim
	1410	Traffic Analysis	14-Sep-09	7-Dec-10	1,000	1,000	Schedule	Jane
	1412	Video Simulation	14-Sep-09	7-Dec-10	1,000	1,000	Budget ($)	Ed
	1411	Urban Design	14-Sep-09	7-Dec-10	1,000	1,000	Budget ($)	Chu
	1407	Safety Audit	3-May-10	27-Oct-10	1,000	1,000	Budget ($)	Carl
	1404	Noise and Vibration	14-Sep-09	7-Dec-10	1,000	1,000	Schedule	Ryan
	1408	Partnering	8-Oct-09	7-Dec-10	1,000	1,000	# sessions (2)	John
		Stray Current Analysis			1,000	1,000		

The integrated WBS allowed the development of detailed cash-flow projections on a monthly basis for the project duration, while at the same time created the baseline for the EVM approach. This provided the City with reliable cash-flow projections for financing.

4.1.2.2 Progress

To facilitate the progress measurement approach, detailed drawing lists were prepared by each discipline on the project. At the outset of detailed design each design discipline that had a contribution to the detailed design drawing submission prepared a list of all drawings (including number and name of drawing) that were required for their specific area of the design. For example, the roadways designer would develop a list of all design drawings that were required for all roadwork on the project. Over 3100 drawings were recorded on these lists and their progress updated on a weekly basis by the respective disciplines according to the progress increments described in **Table 23.**

It should be noted that the drawing list did not include or track specifications. This resulted in a slight progress over estimation during the final months of the project where drawings were nearing completion but specifications were still being refined. The proposed approach in **Section 3.3** recommends that specifications and reports are included in this list of deliverables, to account for this. The drawings list also gave equal weighting to each of the drawings, which proved to be an inaccurate assumption. Some drawings are the 'path makers' and require considerable effort and others may be simple duplications of the same drawing. The proposed approach was subsequently revised to allow for effort weightings for each drawing to be assigned.

Table 23 – Progress measurement milestones for drawings

Base Work (5%)	Establishing base plans and contract plans, acquiring information, and any preparatory work that must be completed before a drawing is officially started. This stage was developed to account for the less tangible work that occurs to facilitate drawing progress and to give a more accurate representation of progress at the beginning of a project;
Started (15%)	When work on a drawing has officially started;
Progress (50%)	Work on a drawing is progressing toward 70%. At times, drawings are started but are put off for a variety of reasons, where no progress is being made. In order to account for this circumstance, a drawing enters the Progress stage only when significant work has been completed on it.
70% Design (70%)	When a 70% drawing is submitted for approval.
Substantial Progress (80%)	Drawings that have been approved at 70% and are progressing significantly toward 95% submission.
95% Design (95%)	When a 95% drawing is submitted for approval.

Complete (100%)	When a drawing is submitted for 100% approval and is ready for construction.

These milestones were subsequently refined, as shown in Section 3.3. The revision was that the “Progress” milestone was dropped to 40% weight because progress tended to be overly optimistic at this stage during detailed design.

4.1.2.3 Reporting

EVM was reported on a monthly basis to the design team and City and this was a challenge in and of itself. The coordination and forethought required to gather all necessary cost and progress information to allow for timely EVM was significant. All consultants on the project were contractually required to provide monthly invoicing by the 10th of each month. This information was compiled and input to the EVM analysts.

The EVM was provided as a dash-board view of the project cost and schedule performance, complete with monthly trends and color coded status indicators.

As such, a status indicator technique is added to the EVM reporting to provide at-a-glance performance results. This involves the four level color coding system provided in **Table 24**. This system is simple and sufficient for the purpose of directing attention where it is required. Anything performing at or above the plan would have a status of "Green" and would not need to be discussed. Anything "Yellow" is performing slightly behind schedule or over budget and investigation into the task is warranted. Items that are performing in the "Red" for cost or schedule require immediate review and corrective action and should be monitored closely until back on track. Items that fall into "Black" status are considered critically off track and need to be reviewed immediately to determine feasibility of the item and its plan.

Table 24 - EVM Status Indicators

GREEN = On track
YELLOW = Slightly behind schedule or over budget
RED = Needs immediate attention
BLACK = Critical/Needs review of item and plan

The EVM was reported in two phases to allow for timely corrective action on poorly performing tasks. The first phase, the Preliminary EVM, was provided to the design team for review and investigation into any poorly performing areas before the report was provided to the City. The results of this detailed investigation were recorded and compiled into the Final EVM. An example of the EVM report provided to the City on a monthly basis is shown in **Figure 27**.

These monthly progress driven EVM reports were part of a complete progress report containing financial updates, risk management updates, design discipline reports, and construction updates. A monthly meeting was held with the City and project management team to review the report in detail.

Table 2 - Team North LRT Earned Value Analysis

Task Name	Earned Value Analysis (Aug, 2010)																	
	% Comp	% Budg. Spent	Total Budget	Spent $ Total	Spent $ Period	CV	SV	CPI (Period)	CPI (Project)	Trend	SPI (Period)	SPI (Project)	Trend	FAC	FVAC	Cost Status	Sched. Status	
1000 - Project Management	77.0%	54.3%	$1,000,000	$1,000,000	$1,000,000	$588,590	$0	1.32	1.42	–	1.00	1.00	–	$1,000,000	$764,403	GREEN	GREEN	
1100 - Project Controls	72.0%	65.9%	$1,000,000	$1,000,000	$1,000,000	$55,914	-$9,187	1.00	1.09	–	1.00	0.99	–	$1,000,000	$74,388	GREEN	GREEN	
1200 - Quality Management / QC	75.0%	71.7%	$1,000,000	$1,000,000	$1,000,000	$22,958	$0	0.96	1.05	–	1.00	1.00	–	$1,000,000	$30,610	GREEN	GREEN	
1300 - Management Support	76.0%	58.9%	$1,000,000	$1,000,000	$1,000,000	$220,261	$0	0.74	1.29	↓	1.00	1.00	–	$1,000,000	$289,817	GREEN	GREEN	
1400 - Design Support Services	50.6%	27.7%	$1,000,000	$1,000,000	$1,000,000	$179,580	-$163,863	0.21	1.83	↓	0.54	0.71	–	$1,000,000	$0			Item will be monitored but will not contribute to performance.
1500 - Commissioning	77.0%	66.3%	$1,000,000	$1,000,000	$1,000,000	$61,874	-$1,120	0.71	1.16	↓	1.00	1.00	–	$1,000,000	$80,068	GREEN	GREEN	
1600 - Environmental Services	100.0%	74.2%	$1,000,000	$1,000,000	$1,000,000	$58,722	$50,110	0.00	1.35	↓	0.00	1.28	↓	$1,000,000	$58,722	GREEN	GREEN	Environmental services complete.
1700 - Geomatics	92.4%	85.2%	$1,000,000	$1,000,000	$1,000,000	$17,358	$30,441	1.03	1.08	–	0.24	1.16	↓	$1,000,000	$21,114	GREEN	GREEN	
1800 - Geotechnical	96.0%	96.0%	$1,000,000	$1,000,000	$1,000,000	$66	$102,384	1.00	1.00	–	0.63	1.22	↓	$1,000,000	$4,343	GREEN	GREEN	
D100 - Roads	73.0%	49.6%	$1,000,000	$1,000,000	$1,000,000	$333,047	-$8,350	1.16	1.47	–	0.66	0.99	↓	$1,000,000	$454,130	GREEN	YELLOW	Progress in August slowed due to holidays. Resource have been added.
D200 - Drainage	65.0%	44.1%	$1,000,000	$1,000,000	$1,000,000	$167,235	-$96,436	0.86	1.48	↓	0.55	0.84	–	$1,000,000	$222,072	GREEN	RED	Additional effort applied.
D300 - Landscape Architecture	80.0%	50.1%	$1,000,000	$1,000,000	$1,000,000	$189,362	-$16,221	0.91	1.60	↓	1.15	0.97	–	$1,000,000	$234,162	GREEN	YELLOW	Additional effort applied.
D400 - Structural	60.0%	76.7%	$1,000,000	$1,000,000	$1,000,000	-$437,757	-$407,023	0.53	0.78	↓	1.23	0.80	↑	$1,000,000	-$1,076,426	RED	RED	ROW Structure drawings (~40) awaiting final input from Roads, Landscape, Catenary, etc. May require schedule extension.
D500 - ROW Electrical	71.0%	74.3%	$1,000,000	$1,000,000	$1,000,000	-$9,542	-$27,597	-0.43	0.96	↓	-0.26	0.88	↓	$1,000,000	-$25,234	YELLOW	YELLOW	Drawings added in August.
D600 - Buildings	80.0%	82.6%	$1,000,000	$1,000,000	$1,000,000	-$69,525	-$31,737	0.64	0.97	–	0.50	0.99	↓	$1,000,000	-$95,101	YELLOW	YELLOW	Nait Station issues could pose future delays. Delay in August due to holidays.
D700 - Traction Power & Catenary	78.0%	56.7%	$1,000,000	$1,000,000	$1,000,000	$192,665	-$22,834	-1.21	1.38	↑	0.26	0.97	↓	$1,000,000	$242,326	GREEN	YELLOW	Progress slowed in Aug due to holidays.
2800 - Track	71.0%	62.1%	$1,000,000	$1,000,000	$1,000,000	$131,855	-$130,621	0.00	1.14	↓	0.00	0.89	↓	$1,000,000	$139,080	GREEN	YELLOW	Reworking 106St crossover, developing plinth calculation program, and incomplete drawing list updating.
3100 - Signals	87.0%	54.3%	$1,000,000	$1,000,000	$1,000,000	$23,308	$4,776	0.00	1.60	↑	1.54	1.08	–	$1,000,000	$27,236	GREEN	GREEN	
3200 - Communication Systems	84.0%	84.0%	$1,000,000	$1,000,000	$1,000,000	-$815	$131,248	2.00	1.00	↑	3.07	1.07	↑	$1,000,000	$24,039	GREEN	GREEN	May require extension due to dependence on other tasks.
3500 - Utilities	87.0%	63.0%	$1,000,000	$1,000,000	$1,000,000	$155,559	$43,383	3.09	1.38	↑	1.68	1.08	↑	$1,000,000	$183,496	GREEN	GREEN	
3700 - NAIT Concept Plan	100.0%	63.7%	$1,000,000	$1,000,000	$1,000,000	$91,889	$0	0.00	1.57	–	0.00	1.00	–	$1,000,000	$91,889	GREEN	GREEN	Nait concept design complete.
Team North LRT (Less Disbursements)	**75.3%**	**66.4%**	**$1,000,000**	**$1,000,000**	**$1,000,000**	**$1,972,602**	**-$552,648**	**0.89**	1.13	–	**0.99**	0.97	–	**$1,000,000**	**$1,745,133**	GREEN	YELLOW	Project may require schedule extension for select tasks.

Terminology

Cost Performance Index	CPI	Budget at Completion	BAC
Schedule Variance	SV	Actual Cost	AC
Schedule Performance Index	SPI	Earned Value	EV
Forecast at Completion	FAC	Planned Value	PV
Variance at Completion	FVAC	Cost Variance	CV

Status

GREEN = On track	>1.0
YELLOW = Slightly behind schedule or budget	>0.85
RED = Needs review	>0.65
BLACK = Needs immediate attention	<0.65

Further details provided in Table 3

Figure 27 - A sample EVA "dash-board" report indicating the performance of each work-package during the design phase. The color coded status indicators allow for at-a-glance prioritization of management attention. The arrows indicate the trend of the item relative to last month's performance and the comments are results of detailed investigation into poorly performing tasks. This report was presented to the City on a monthly basis.

The figure provided below (**Figure 28**) displays a typical EVA graph used to communicate the overall health and forecast of the project.

This figure shows several important pieces of information:

1. From inception the project has been progressing faster than it has been spending (the red line is under the green line in every period)
2. Progress has been very close to the plan in each period, but is showing signs of falling slightly behind in the final months (the green line is starting to drop below the blue line in later months)
3. The forecast to complete the project is showing that it is likely to extend into January (the green dotted line is showing that it reaches completion in January, one month later than the original plan)

4. The project will be completed under budget (the dotted red line terminates below the dotted green line)

5. The jog in the graph in May indicates where the project was re-baselined and re-structured, due to a City-directed scope change, in order to show a more realistic picture of progress. As can be seen the figure became more stable after this point.

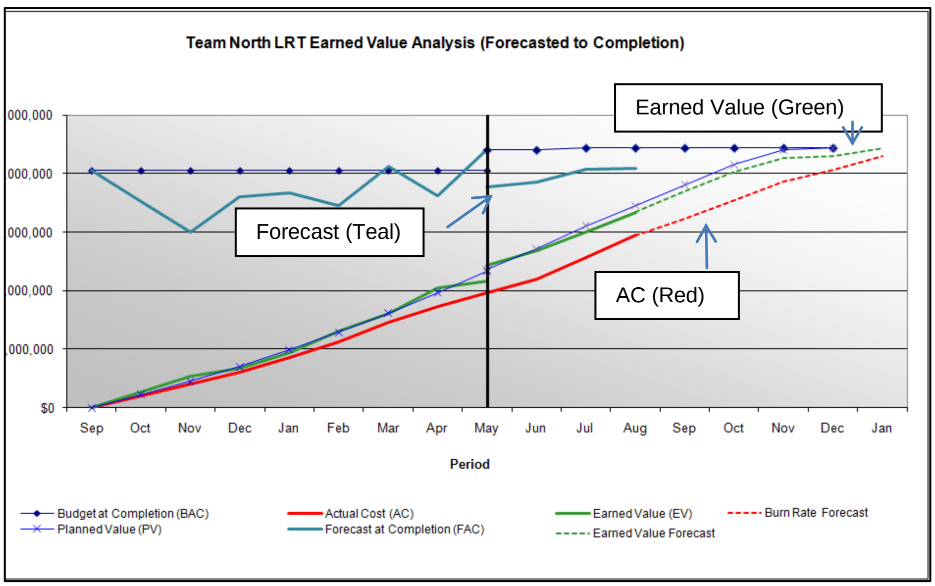

Figure 28 - Typical EVA Figure showing the relationship and trend between actual progress (green), AC (red), Planned Progress (blue), Forecasted Cost at Completion (teal). Note that the y-axis units have been removed for sensitivty purposes.

These figures were provided to the City and management team on a monthly basis, so that timely decisions could be made to mitigate potential schedule overrun or to reallocate funding to support value added activities.

4.1.2.4 Forecasting

A key feature of the EVM reports was the forecasting of final project cost and schedule. EVM forecasting is one of the most useful components of this type of performance monitoring. It provides an educated and transparent look into the future outcome of a project given what is known at the present time. In this way, it makes real the impact of not correcting an action and lets the owner know what to plan for at completion.

There are a variety of techniques that can be used in forecasting and each has its benefits at certain times and for certain scenarios. Forecasting on the NLRT was undertaken using proven and state-of-the-art techniques and was customized to suit the specific scenario for each individual task on the WBS. In general, the combined cost and schedule index approach was used for forecasting throughout the project.

$$EAC = AC + \frac{BAC - EV}{FPI} \qquad \text{Equation 48}$$

$$FPI = CPI_{cumulative} \times SPI_{cumulative} \qquad \text{Equation 49}$$

This approach was sufficient, but it was seen that the forecast at the initial stages were very unstable. This could have been rectified by setting the FPI to 1.0 for the first few periods of the project, as is suggested in this thesis.

Benefits that were realized on this project due to the EVM approach were twofold: schedule, and cost. The following illustrates these benefits.

4.1.2.4.1 Examples of EVM Schedule Control Benefit

In mid-summer 2010, the project schedule used for identifying when the project was expected to complete, showed that the design was expected to complete in

December 2010 – on approved schedule. In the same period, the EVM exposed a risk of schedule overrun.

The EVM schedule forecast began to show a slippage from the intended December completion date into January 2011. After detailed investigation, it was identified that only a select few disciplines were causing this schedule overrun. The management team and City were able to determine that this schedule extension would not have an impact on the desired construction schedule and as such the project was extended to January 2011. This allowed enough time for lagging disciplines to complete their work without major acceleration (and resulting costs). However, the major benefit was that it allowed additional time for many of the other disciplines to dedicate time to completing 100% drawing sets and specifications before final submission, thereby reducing the risk of encountering design issues during construction. This forecast also provided the foresight needed to reschedule the construction procurement phase that was to commence at the end of detailed design. This effectively avoided a major scramble that would likely have occurred as the procurement deadline approached and design/specification were not complete.

Connected with the schedule item described above, a key in allowing the schedule to extend to January 2011 was the assurance that the team could absorb the schedule extension in the existing budget. This was confirmed by the EVA forecasting which continually showed that the project would be under budget by the original December 2010 deadline.

4.1.2.4.2 Example of EVM Cost Control Benefits

In August 2010, 10 months into a 15 month project the existing cost and schedule controls on the project showed that Roads and Structures had spent between 50% and 77% of their budgets as shown in **Table 25**.

Table 25 – Existing project controls information showing percent of budget spent

Accounts	% Budget Spent
D100 - Roads	49.6%
D400 - Structural	76.7%

From this information, the management team can not readily interpret if there is anything wrong or if each item is on track to finish on budget. To stretch the value of these controls, if managers were to look into the details, they could interpolate based on the completion of 10 of 15 months on the project that each item should be around 75% complete. This would raise a flag that Roads may come in under budget, but by how much is unknown. It would also be supposed that Structural design is roughly on-target and no issue would be identified.

The EVM approach; however, showed considerably more insight into what was actually occurring. In **Table 26**, it can be seen that Roads is 73% complete compared to the 50% spent and that this is forecasting a $454,130 underrun; information that is very useful to the project team and owner in future planning and is not exposed through traditional methods.

The key issue that is exposed with the EVM approach relates to the Structural account. The Structural account is only 60% complete in terms of the finishing the deliverables (drawings). When compared to the budget spent to-date of 77%, this is alarming. The EVM goes further to forecast the impact of current performance, resulting in a $1,076,426 projected overrun at completion.

Table 26 - EVM information showing physical percent complete and forecasts

Accounts	Physical % Complete	% Budget Spent	Forecasted Cost at Completion	Variance at Completion
D100 - Roads	73.0%	49.6%	$969,390	$454,130
D400 - Structural	60.0%	76.7%	$3,699,246	-$1,076,426

As can be seen, the traditional controls indicated that that the Structural account was roughly on target and the EVM showed that it was expected to be a million dollars over budget. This demonstrates significant benefits of the EVM.

To further validate this example, the final cost variances at completion these items were as shown in Table 27. Roads ended up $252,805 under budget. Structural ended up spending $431,192 over budget.

Table 27 - Comparison between forecast and final costs

Accounts	Forecasted Variance at Completion	Actual Variance at completion
D100 - Roads	$454,130	$252,805
D400 - Structural	-$1,076,426	-$431,192

Note that due to the actions that may have been taken to reduce forecasted variances between the time of forecast and end of project, one cannot strictly validate or invalidate a forecast by comparing to the final result. What is purported to be shown with this forecasting comparison is:

- The EVM forecast indicated a significant underrun for Roads and a significant underrun was realized. The traditional cost control did not show a forecast and did not raise any flags. A value of exposing this underrun is that when management or owners can see that budget will be remaining at project completion, they may wish to implement additional value added work or may be able to use the funds elsewhere to reduce overruns, mitigate risks, etc.

- The EVM forecast for Structural indicated potential for a significant overrun. Once the team was aware of this, actions were taken to reduce that overrun. These actions included: identifying that key decisions were preventing Structural drawing from progressing; raising awareness within the structural team that efficiency needed to improve; and detailed resourcing of the remaining Structural design. This reduced the projected variance by 60% by the end of the project. The traditional cost control being used indicated that structural was on-target at the time of the EVM forecast.

Overall, the EVM allowed additional value added, risk reducing tasks to be undertaken within the existing budget. The EVM consistently indicated that the design was going to be under-budget. This lead to the absorption of value added tasks into the design budget that would have otherwise either not been undertaken or been change orders to the budget. Several important tasks that were absorbed into the budget were:

- Project Implementation Plan Development: this was a key in the RFP process for construction. Clearly delineating the responsibilities of the Engineer, Construction Manager, and City for the pre-construction and construction phase of the project. It has proven to be a very useful tool during construction.

- Preparation of RFQ and RFP documents related to Construction Management and other related contract documents were absorbed into the budget.
- Overhead costs incurred from the extended schedule
- Keeping key project team members on the project during the interim months between design completion and start of pre-construction activities.

The traditional controls did not provide a forecast of end results and so could not have added this value to the project.

4.1.2.5 Summary Discussion:

The NLRT concluded on approved budget and schedule with significant value-added measures that would help the construction phase off to a smooth start. This case study provides the first attempt at implementing the EVM approach on the engineering work in design. It demonstrates that compared to the current/traditional cost and schedule controls, the EVM provides significant value in terms of measuring physical progress and projecting project outcomes. This case study proves that EVM can be implemented successfully on engineering work when it is customized to the engineer effort.

The owner and engineering team on this project were so impressed with the level of control, insight, and transparency that the EVM approach offered that the same approach was adopted for the next phase of the project — the construction phase. The owner had this quote regarding the EVM project controls:

“The project controls team has utilized best practices to provide the project management team with the information needed to make key decisions on schedule management, cost management, resource allocation, and project scope, on a continuous basis” (City Project Manager for the North LRT Detailed Design, September, 2011).

4.2 North LRT Construction

The NLRT Construction project was undertaken as a combination of different contracts. The main construction component of the project was contracted as a Construction Manager — at-risk contract. The other major contract was the rail signals portion of the work which was contracted as a design-build. There were also a variety of smaller portions to the work, some undertaken with the City's internal departments and others undertaken by smaller miscellaneous contracts. The engineering team acted as the owner's consultant and manager of the overall project.

At the time of the case study's development, the project had progressed for 11 months of the roughly 36-month expected duration. The following sections discuss the details of how the system was implemented, a comparison between the existing cost and schedule controls on the project, and the success that has been realized so far.

4.2.1 Work Breakdown Structure

The WBS for the engineering work was developed at the outset and is used for cost accounts only. The schedule feature of the engineering work during construction is not necessarily required. The schedule is completely dependent on the construction schedule for the project. In this way, there is more freedom for the engineering work to develop a WBS that is suited for the cost accounting system only. This is something that is not the case during design work, where the design schedule is very important and should be integrated with the WBS and cost accounting system.

The WBS breaks the engineering work down in terms the type of work and each individual design discipline is separated from the other in order to allow for proper control and assignment of responsibility. The second level of this WBS is developed based on the resources on the project. This approach ensured that an individual resource (person) would only be required to charge to a single account. The design discipline in particular (Accounts 10 to 26) were broken down into three general categories: Monitoring, Coordinator, and Discipline Support. This breakdown was chosen purposefully to allow project controls to track the amount of time spent on monitoring. This monitoring time was of particular importance on the project because of the Construction Manager contracting strategy. In this form of contract the engineer is expected to do less monitoring and site inspection and rely on the systems put in place by the construction manager to verify quality and design intent. The engineer's role in this regard was as more of a weekly monitor rather than a daily inspector. However, this is very different from the traditional role of the engineer who is more comfortable having a higher level of involvement in ensuring that the design intent is met and the quality of the work is adequate. In an attempt to track the amount of time spent monitoring, the WBS was broken down as such. The control accounts on this WBS were established at the lowest level shown in order to better have a handle on the various aspects of the project and to be able to pinpoint were performance is deviating from the plan.

In hindsight, it was shown that the breakdown as proposed in **Section 3.1** (monitoring work and contract administration) would have been more suitable. The coordinator and discipline support portions to WBS that was used resulted in mischarging and confusion of resources. Most Design Discipline (level one on the WBS) were dedicated to a single engineering firm as proposed in the **Section 3.1**; however, the few that contained more than one firm did pose problems for pinpointing the cause of an EVM variance when it arose. This confirms the proposed approach to ensure that control accounts are dedicated to one engineering firm only.

A sample of this WBS is provided in **Table 26**.

Table 28 – Sample of WBS for engineers contract

Tasks
1 Project Management
1.1 Project Management
1.2 Project Advisors
1.3 Project Support
………..
16 Heavy Civil
16.1 Engineering Coordinators
16.2 Engineering Monitors
16.3 Discipline Support
17 Landscape
17.1 Engineering Coordinators
17.2 Engineering Monitors
17.3 Discipline Support
18 Roads
18.1 Engineering Coordinators
18.2 Engineering Monitors
18.3 Discipline Support
……….
9 Disbursements
9.2 Recoverable
9.1 Disbursements

4.2.2 Baseline Development

4.2.2.1 Existing cost and schedule control

Existing controls on the project developed a budget for each of the work-packages in the WBS. This process involved assuming a construction schedule for each of the design disciplines (not based on the actual construction schedule as it was not available at the time of estimating costs). From this schedule they estimated the number of resources that were expected (e.g one monitor, one coordinator for roadworks). The budget for each discipline was phased on a yearly basis and budgets were then set.

This process did account for the expected construction schedule but did not show these assumptions clearly and budgets were not linked to the actual construction schedule. It was also planned out on a yearly basis. The budgets expected to be spent month to month were not developed.

4.2.2.2 EVM Approach

Being a construction project, the baseline for engineering work had to account for the construction schedule. The engineering work does not therefore have its own schedule to control from, but rather is completely dependent on the schedule developed by the construction manager and its contractors. This baseline development occurred using an excel template where the WBS items were listed down the left side and the schedule for the relevant construction accounts shown across the top. Each control account manager performed the task of planning their level of effort (budget distribution) according to the construction schedule. An example of this exercise is shown in **Figure 29** for the Drainage account.

Task	Sub	Role	Task Description	May-11	June-11	July-11	August-11	September-11	October-11	November-11
			Related Construction Schedule	Kingsway Removals						
					Kingsway Package					
					Miscellaneous Paving Package					
						Roadworks (except Kingsway)				
Discipline : Drainage										
13		**13 Drainage**								
	13.2	**13.2 Engineering Monitors**		**$ 9,900.00**	**$ 9,900.00**	**$ 15,840.00**	**$ 15,840.00**	**$ 15,840.00**	**$ 15,840.00**	**$ 15,840.00**
			Pre-construction Activities	$ 9,900.00	$ 9,900.00					
			Construction Activities			$ 15,840.00	$ 15,840.00	$ 15,840.00	$ 15,840.00	$ 15,840.00
			Post-Construction Activities							
	13.3	**13.3 Discipline Support**		**$ 5,425.00**	**$ 5,425.00**	**$ 4,030.00**	**$ 4,030.00**	**$ 4,030.00**	**$ 4,030.00**	**$ 4,030.00**
			Pre-construction Activities	$ 5,425.00	$ 5,425.00					
			Construction Activities			$ 4,030.00	$ 4,030.00	$ 4,030.00	$ 4,030.00	$ 4,030.00

Figure 29 – Sample baseline development template used to distribute the engineer's budget over the construction schedule (values are shown for illustration purposes and do not reflect the actual values used)

It should be noted that this approach is similar to what is proposed in **Section 3.1**, but the proposed approach is to link the design disciplines to the construction packages explicitly instead of just using the construction packages as information when planning (as is shown in **Figure 29**). This proves benefits when it comes to maintaining the baseline when the construction schedule changes. There is an explicit link between the engineer's baseline changes that result from a construction schedule change.

Once this exercise is completed the baseline monthly PVs are created as depicted in **Figure 30**. As can be seen, the work takes on the non-uniform distribution when planned using the actual construction schedule. This is a more realistic distribution than the typical approach of uniformly distributing the budget over the schedule. This approach is particularly important for engineering work because the WBS cannot realistically be broken into the same amount of detail as construction work. This lack of detail makes the uniform distribution an inappropriate assumption to make when planning the level of effort.

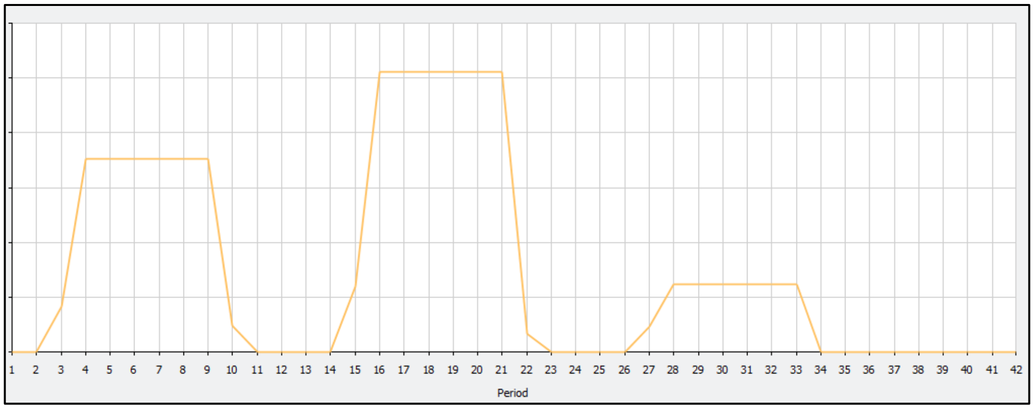

Figure 30 – Monthly planned budget expenditures (PVs) for drainage work (the y-axis is in units of dollars. Values have been removed from the y-axis for sensitivity purposes).

This exercise is undertaken for all items on the engineer's WBS to produce the overall PVs for the engineering portion of the project. This is depicted in **Figure 31**. As can be seen, the distribution does not follow the typical effort expected in EVA. Generally effort is expected to be slow at the beginning and end of the project and increase during the middle sections. On this project, the planned effort was expected to be the highest at the beginning to get the project started, then settle down to a relatively even pace and as expected drop off considerably towards the end.

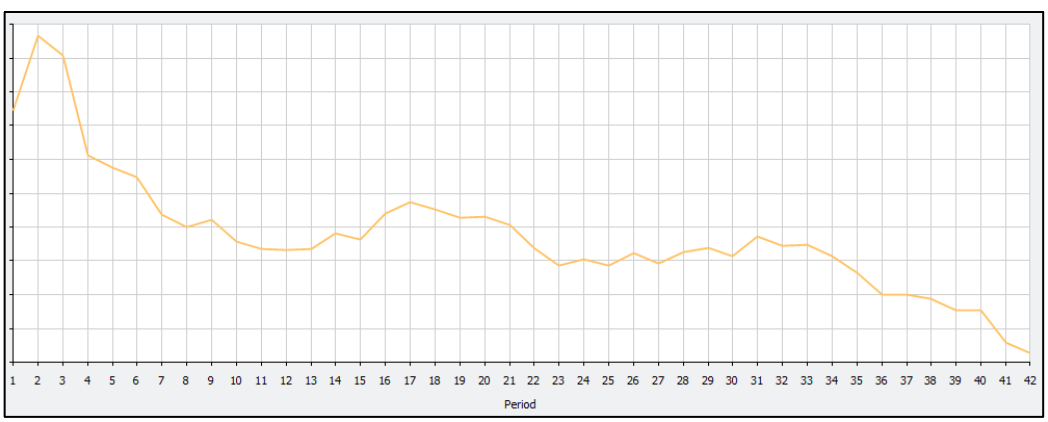

Figure 31 – Overall monthly budget expenditures (PVs) for the engineering effort (the y-axis is in units of dollars. Values have been removed from the y-axis for sensitivity purposes).

This technique for planning the engineering work proved to be very useful in documenting the assumptions that were made by the engineers in planning their budgets and provided believable reasoning for deviations in the budget when the respective engineering work did not go according to the baseline schedule. It is well known that engineering work, and consequently engineering budget, is highly subject to construction progress. If construction progress is slower than expected, the engineer increases the risk of budget overrun because the engineers is required to be around until construction is complete. Because all assumptions were clearly laid out when the engineer planned the work, there is more ground to stand on when asking for additional budget due to construction delays or vice versa (returning budget because construction occurred faster than anticipated and the engineering effort was not required as long).

4.2.3 Baseline Maintenance

The baseline discussed above is maintained through two primary processes: scope change management and re-baselining. The first process, scope change management, was handled through the project wide change order process. This involved a set of forms that tracked any suggested innovations to the design (Proposed Innovation), or required changes to the design or scope (Notice of Potential Change). Each time one of these forms was filled out, the expected impact on the engineering design modifications budget and related monitoring budget were estimated. If the change was approved through a formal change order, the respective engineering budgets were adjusted accordingly. The second process for baseline maintenance, re-baselining, occurred on a yearly basis. An analysis of the construction progress compared to the engineering progress and expenditures and a plan was then set for the next year. This plan included re-planning of the remaining budget based on the latest revised construction schedule.

The information that was provided through the formal change process did not reliably provided all information required to update the EVM baseline. The schedule for the changes was the missing component. This implied the traditional assumption that the change order applied from start date to end date of the control account, which is often not the case. The proposed approach in **Section 3.2.2** was refined to specify that the schedule implications of the change order to each control account be specified.

4.2.4 Progress and Earned Value

4.2.4.1 Existing Controls

The existing controls for the engineering work, did not measure physical progress of the engineering work in any respect, except percent of budget spent.

4.2.4.2 EVM Approach

Progress for each engineering control account was customized based on the progress measurement approach discussed in **Section 3.3.2.3.3** of this document. Progress measurement used on this project was classified into four categories:

- Management related work
- Design discipline/EOR related work
- Drawing based work
- Other

Progress for management related tasks:

- Pre-construction: use preset monthly progress increments based on planned expenditures for months leading up to construction (until May-11).
- Construction: linked to number of months of construction according to the baseline construction schedule (June-11 to Dec-13). Progress will be calculated based on number of construction months complete divided by forecasted total number of construction months.
- Post-construction: use preset monthly progress increments based on planned monthly expenditures (Jan-14 until end).

An example of this is shown in **Figure 32**.

Management Progress Calculator														
			Pre-construction				Construction	Post Construction						
	Weight	Start	Pre-const. 1	Pre-const. 2	Pre-const. 3	Pre-const. 4	Const. 1	Post Const. 1	Post Const. 2	Post Const. 3	Post Const. 4	Post Const. 5	Post Const. 6	Current %	Percent Complete
			Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14		
Construction months completed							*7*								
Forecasted Construction months							*31*							*check*	
	PM Weight	*0%*	*3.1%*	*4.1%*	*3.9%*	*3.2%*	*82.4%*	*1.0%*	*1.0%*	*0.8%*	*0.3%*	*0.3%*	*0.0%*	*100.0%*	
	PA Weight	*0%*	*0.7%*	*13.8%*	*23.8%*	*8.2%*	*50.5%*	*1.0%*	*0.7%*	*0.3%*	*0.6%*	*0.32%*	*0.00%*	*100.0%*	
	PS Weight	*0%*	*2.7%*	*3.5%*	*4.3%*	*3.5%*	*83.4%*	*0.9%*	*0.9%*	*0.7%*	*0.0%*	*0.00%*	*0.00%*	*100.0%*	
	CC Eng Weight	*0%*	*2.6%*	*3.4%*	*4.3%*	*3.4%*	*84.9%*	*0.6%*	*0.6%*	*0.1%*	*0.0%*	*0.00%*	*0.00%*	*100.0%*	
	CC Con Weight	*0%*	*3.5%*	*4.1%*	*3.8%*	*3.4%*	*71.3%*	*2.3%*	*2.3%*	*2.3%*	*2.3%*	*2.34%*	*2.25%*	*100.0%*	
	RM Weight	*0%*	*0.9%*	*3.1%*	*3.5%*	*3.1%*	*74.5%*	*2.5%*	*2.5%*	*2.5%*	*2.5%*	*2.47%*	*2.47%*	*100.0%*	
	DM Weight	*0%*	*2.0%*	*2.6%*	*3.3%*	*2.6%*	*86.0%*	*1.3%*	*1.3%*	*0.8%*	*0.0%*	*0.00%*	*0.00%*	*100.0%*	
Project Management	***100.00%***														***35.54%***
Project Management	51.3%	0.0%	3.1%	4.1%	3.9%	3.2%	*18.6%*							32.9%	16.9%
Project Advisors	10.7%	0.0%	0.7%	13.8%	23.8%	8.2%	*11.4%*							57.9%	6.2%
Project Support	38.0%	0.0%	2.7%	3.5%	4.3%	3.5%	*18.8%*							32.8%	12.5%
Project Controls	***100.00%***														***30.11%***
Cost Control - Engineering	21.7%	0.0%	2.6%	3.4%	4.3%	3.4%	*19.2%*							32.9%	7.1%
Cost Control - Construction	34.3%	0.0%	3.5%	4.1%	3.8%	3.4%	*16.1%*							30.9%	10.6%
Risk Management	32.5%	0.0%	0.9%	3.1%	3.5%	3.1%	*16.8%*							27.5%	9.0%
Document Management	11.4%	0.0%	2.0%	2.6%	3.3%	2.6%	*19.4%*							30.0%	3.4%

Figure 32 – Sample progress measurement for the management related work used on the NLRT construction project.

The lesson that is learned from this approach is that the pre-construction and post-construction progress increments need not be used. The engineering progress is better tracked using the method proposed in **Section 3.3.2.3.3** (number of months complete, direct apportioning to construction, or relational apportioning to construction progress) or even better the method of linking management progress non-linearly to procurement and construction progress.

Progress for design discipline/EOR related work is broken into three sections as discussed below:

- General Participation and Support: 10% to 20% progress distributed evenly over the planned monitoring schedule (from start of procurement on related subcontracts and equipment to end of post-construction phase). Weighting will be based on length of schedule and discipline. Note that this progress credit will also be tied to the quality and timing of work that is required on a monthly basis. For example, if a monitoring team is required to respond to five RFI's in the month yet only completed work on three of them, they would not earn full progress for General Participation and Support. Completion of this work would be tracked on SharePoint registry's (SI, NPC, CO, etc.) and by the management team. This has been added at the request of the City.

- Procurement Progress: 15% to 20% progress will be earned through completion of the related procurement items (related subcontract packages and equipment procurement). Increments will be linked to the Construction Manager's procurement progress shown in **Table 29 and 30.**

Table 29 – Construction subcontract procurement progress increments

Milestone	**Weighting**
Review Start	1%
Review Substantial Progress	9%
Drawing Modifications Start	15%
Drawing Mod. Substantial Progress	10%
Issue RFQ	15%
Award RFQ	5%
Issue RFP	5%
Close RFP	15%
Award RFP	20%

Proponent Mobilizing	5%

Table 30 – Material and Equipment Procurement Milestone progress increments

Milestone	Weighting
Started	*5%*
Review Start	*5%*
Review Progressing	*5%*
Procure	*10%*
Award	*10%*
Manufacturing in Progress	*15%*
Manufacturing Complete	*25%*
Pre-Inspection	*5%*
Arrival	*5%*
Final Inspection	*5%*
Acceptance	*10%*

- Construction Control Account Progress: 60% to 75% progress will be earned based on related Control Account progress. Control Account progress will be measured according to the methods described in the Construction EVM. A sample of these methods is provided in **Table 31** for information and clarity.

Table 31 – Roadwork construction progress weighted milestones

Milestone	Weighting
Site Preparation	5%
Removals	20%
Excavation	15%
Sub-base	15%
Asphalt	20%
Surface	20%
Sidewalks	5%

This approach is customized to each account on the engineering WBS. All related procurement and construction packages are linked to the respective account on the engineers WBS. Weighting for each procurement and construction package were developed using the budgets for these accounts. As construction or procurement progress is made each period, the engineer's progress is updated accordingly. Refer to **Figure 33** for an example of this form of progress measurement that was used for the Drainage package on the WBS.

In this example, progress is awarded up to the current month of December 2011. General Participation and Support is 36% complete (9 working months completed of a total of 25), contributing 5.4% to the total progress. Procurement progress is 100% complete, contributing 15% to the total progress. Related construction progress is 51.1% complete, contributing 35.8% to the overall progress. The total progress for drainage work is therefore 56.2% complete.

Total Progress	Weight	General Participation		Current %	Percent Complete	Weight	Drainage Percent Complete
56.2%		Start	End				
		Apr-11	*Oct-13*				
	Months	*31*					
	No work	*Dec, Jan, Feb*	*6*				
	Work Months	*25*					
	Weight	*100.00%*					
	Increment	*4.000%*					
	Current Month	***Dec-11***					
	Months expended	*9*					
Gen. Participation	*100.00%*			*36.00%*	*36.00%*	*15.00%*	*5.4%*
Procurement	*100.00%*				*100.00%*	*15.00%*	*15.0%*
9-Removals (Kingsway)	1.00%			100.00%	1.00%		
10 - Kingsway	5.00%			100.00%	5.00%		
11-SEM Tunnel	10.00%			100.00%	10.00%		
13-Underground Ducts and Utilities	44.00%			100.00%	44.00%		
14 - Roads	40.00%			100.00%	40.00%		
Control Accounts Construction	*100.00%*				*51.12%*	*70.00%*	*35.8%*
12 - Drainage	98.32%			52.0%	51.1%		
22.05 - Tail Track Drainage	1.68%			0.0%	0.0%		

Figure 33 – Progress calculations for Drainage work. Progress was received in three area: General Participation, Procurement, and Control Account Construction progress.

Drawing base progress was used for the WBS account involved in developing record drawings. The work in this account involved converting the 2704 drawings into record drawings as construction as-builts were submitted by the construction manager. The drawings were grouped into categories as shown in **Figure 34** for progress tracking purposes. Each category was awarded progress based on three milestones as shown in the figure. The weighting for each drawing category was determine based on the number drawings in the category compared to the total number of drawings. Progress within each milestone was awarded based on a completion of individual drawings within that milestone. This means that the percent complete awarded to each category within each milestone was not limited to the milestone weight, interim progress was allowable. This interim progress was calculated based on the number of drawings completing that milestone within each category. As shown in **Figure 34,** at the time of this case study, all drawing categories except Traction Power and Catenary were completed the first milestone. Additionally, progress is beginning to be awarded in the second milestone for mist categories. The total progress amounts to 11.3%.

Drawing Section		Weight	As-built (red-line) drawings received	Record Drawings Started	Record Drawing Complete	Current %	Percent Complete
			10%	70%	100%		
			10%	60%	30%		
Drawings Progress	**2704**	*100%*					**11.27%**
General1	*194*	*7.17%*	*10%*	*4%*		*14.0%*	*1.00%*
General2	*109*	*4.03%*	*10%*	*7%*		*17.0%*	*0.69%*
Tunnel and Portal	*146*	*5.40%*	*10%*	*1%*		*11.0%*	*0.59%*
Churchill Station	*14*	*0.52%*	*10%*	*9%*		*19.0%*	*0.10%*
MacEwan Station	*203*	*7.51%*	*10%*			*10.0%*	*0.75%*
Kingsway Station	*156*	*5.77%*	*10%*			*10.0%*	*0.58%*
NAIT Station	*74*	*2.74%*	*10%*			*10.0%*	*0.27%*
Roads	*165*	*6.10%*	*10%*	*4%*		*14.0%*	*0.85%*
Drainage	*100*	*3.70%*	*10%*	*5%*		*15.0%*	*0.55%*
Landscape	*106*	*3.92%*	*10%*	*1%*		*11.0%*	*0.43%*
Track	*206*	*7.62%*	*10%*	*1%*		*11.0%*	*0.84%*
ROW Structures	*96*	*3.55%*	*10%*	*2%*		*12.0%*	*0.43%*
ROW Electrical	*85*	*3.14%*	*10%*	*1%*		*11.0%*	*0.35%*
Communications	*261*	*9.65%*	*10%*	*2%*		*12.0%*	*1.16%*
Traction Power	*127*	*4.70%*	*4%*			*4.0%*	*0.19%*
Catenary	*139*	*5.14%*	*6%*	*1%*		*7.0%*	*0.36%*
Signal, APP	*523*	*19.34%*	*10%*	*1%*		*11.0%*	*2.13%*

Figure 34 – Example of record drawing progress during construction work.

The last progress type, “Other”, captures all the miscellaneous progress measurement techniques that were customized to individual control accounts that did not fit into the techniques discussed above. For example, the Partnering account on the WBS was tracked using milestones for each major workshop and minor “health check” that were scheduled over the course of the project. The weighting for each was based on the budget planned for each workshop or “health check”. Each project contains its own unique features such as these and progress measurement techniques should be customized for individual projects. The proposed approach does not touch on progress for these unique items.

At the time that this case study was compiled, these progress measurement techniques have proved to be effective and accurate for measuring engineering work progress during construction. The monthly and year end review that were undertaken demonstrated that the progress that was being reported was fair and satisfied the “gut-feel” of the engineering team – an important component of proper validation of an academic theory when put into practice.

4.2.5 Actual Costs

Due to the structuring of the WBS, allocation of AC to the proper accounts was only an issue, as mentioned, between the Monitor, Coordinator, Discipline Support work-packages and between the accounts that contained more than one engineering firm.

4.2.6 Analysis, Forecasting, and Corrective Action

4.2.6.1 Existing Controls

Comparison of budget spent to yearly budget for each Design Discipline/EOR work-package occurred on a monthly basis. Schedules were not provided in the monthly reports for the engineer and they only related to construction work.

There were no analysis of performance, no forecasting of project outcomes, and due to this, corrective actions were only initiated when a yearly budget for an individual design discipline was overrun. No pre-emptive measures were taken to identify or control these overruns before they occurred.

4.2.6.2 EVM Approach

Analysis was undertaken on a monthly basis to perform all EVA calculations, forecast end results and develop corrective actions. The typical EVA calculations were as proposed in **Section 3.5.2.2.2.**

Management/continuous tasks were forecasted using the forecast performance index equation:

$$FPI = A(CPI_{cumulative}) + B(SPI_{cumulative}) \qquad \text{Equation 50}$$

Where: A = 70% as a default; and B = 30% as a default.

This was used so that the schedule performance could be accounted for in the forecast (e.g if the scheduled end date slipped, the management team would need to remain on the project). It was found through trial and error that this formula still gave too much weight to the schedule performance (forecast were overly large due to poor schedule performance. The proposed approach was revised to a weighting of 20% for schedule performance to improve upon this.

For discontinuous work (design discipline/EOR), the forecast performance index formulae was:

$$FPI = CPI_{cumulative} \qquad \text{Equation 51}$$

To include SPI in forecasting for the design discipline/EOR accounts would have resulted in skewed forecasts. The Construction Manager owned the float time in the schedule and moved tasks forward and back continually. Engineer's PVs were built off of the baseline schedule and this schedule was subject to continued shifting. This made using engineer's SPI inappropriate for forecasting purposes. The construction schedule still showed the proper end date would be met despite these moves.

The forecasts and trends began to evolve into the primary driver of management attention. Because, there are measuring progress and forecasting for engineering work is not an exact science (uncertainties errors, discrepancies, are inevitable), reliance on trends and forecasting importance was used to help prioritize management attention and corrective action. If an activity was showing an overrun of over 100,000 and this trend was either steady or worsening for several months, this became the focus of discussions and investigations. This prioritization evolved over time and did not have a formal approach to it. This drove the Forecast Criticality Index proposed in **Section 5.5.2.3.** This index is a rather intuitive method to perform this prioritization process through a structured calculation.

To demonstrate the benefits of prioritization process, forecasting in comparison to the existing controls an example is provided.

4.2.6.2.1 Benefits of EVM Approach for Forecasting and Corrective Action

The Communications EOR team was showing a steady forecasted overrun for five straight months.

The existing controls showed that this item was under-budget and a savings was likely to occur for the 2011 budget (this was not explicitly shown but could be deduced by the fact that only 81% of the budget was spent after 10 of 11 months in 2011) (refer to **Table 32**).

Table 32 –Communications EOR work-package information shown from existing cost controls

2011 Budget	AC to Nov-11
42% of total budget	34% of total budget

The EVM on the other hand was showing physical progress to be significantly behind the AC incurred (refer to **Table 33).** Earned Progress was 24%, while the AC were 34% of the total budget. This resulted in a forecasted overrun of $360,000 by the end of the project.

Table 33 – Communications EOR work-package information shown from the EVM approach

2011 Budget	AC to Nov-11	EVM Physical Percent Complete
42% of total budget	34% of total budget	24% of total progress

The EVM had been showing this forecasted overrun for several months prior, but because the existing controls were showing that it was under budget for 2011, the EOR team did not conduct any corrective actions. It was only once the trend became consistent over 5 months that the team gained enough confidence with the EVM approach to implement corrective actions.

The Communications EOR Team was tasked with conducting a detailed review of their account to determine reasons for the variance and corrective actions. The following provides a project excerpt from November 2011 Progress Report (City of Edmonton) and related project controls email.

“There has been concern regarding the status of the Communications spend rate compared to actual progress being made on the NLRT. The following provides a description of the current status:

Communications budget is for both Construction Monitoring/Coordination/EOR effort as well as Design Modifications

- *Design Modifications budget is for specific "Design Modifications" work that is allocated on an as needed basis from NLRT management and is different from the "Construction Monitoring/Coordination/EOR effort"*
- *The Design Modifications progress is unknown and their is potential that effort spent on these is being allocated to incorrectly to Monitoring/Coordination*
- *The Construction Monitoring/Coordination/EOR effort is showing a significant overrun when compared to actual progress and has been tracking progressively worse since the summer*
- *Actual Progress for "Construction Monitoring/Coordination/EOR" is measured based on related construction and procurement progress by the CM as well as a general participation progress of about 1% per month.*
- *Construction and procurement progress has been slower than the CM originally planned, yet the Communications monitoring/coordination budget has continued to be spent at approximately the planned rate*
- *The only track-able NLRT construction work progressing this year related to Communications has been the ductbanks and Churchill Comms room and this has been slower than the original plan (10% to 15% complete to-date versus a plan of 30% complete)*

- *The concern is that Communications has spent 31% of the budget for Construction Monitoring/Coordination/EOR while about 20% of the work is complete. And although the budget is being spent according to the 2011 budget awarded, the related progress is not being made and effort will still need to be expended in the following year when this work actual does commence.*

Response from EOR Team after investigation:

Comments on the reason for the budget/progress discrepancy and solutions to bring the budget more in line with progress:

a. Our original understanding of our budget allocation was that the monitor would receive additional support from our communications engineers, approximately 50 hours per month as needed. This support was included in the task number we also use for Construction Monitoring time.

b. Approximately $X,000 will be moved from Construction Monitoring to NPCs 16, 21 and 22 as they were originally charged to an incorrect task. Additional hours may need to be moved based on further analysis.

c. We calculated that the monitor has charged approximately $X00,000 to Construction Monitoring, or 24%, coming close to the construction progress on site to date at 22%.

d. We reviewed the EVA process and found that there might be missing progress not claimed by the CM – this would account for 1-2% of the difference and would need to be confirmed with Project Controls.

e. Going forward, we believe we will catch up in the coming months through closer monitoring of the budget on a weekly basis and more accurate charges to each change order."

This review and investigation served three purposes: one is that it demonstrated to the monitoring team that there was some concern with the charging to-date verses the progress being made on-site; two it showed the seriousness of the project team to remain on-track in terms of cost and schedule; three it allowed corrective actions to be undertaken to reduce the discrepancy.

The following two periods, with the budget corrections and increased awareness on spending patterns, showed a marked improvement in the EVA results from a status in Black for cost performance and a forecast of $360,000 over-budget to a status in Yellow and a forecasted overrun of $100,000.

Example of Roadworks and Drainage Budget shifts

In late 2011, after a season of road construction, the Roads EOR Team was showing an overrun in terms of planned budget for the year. The team requested that funding be pulled from the 2012, 2013 budget to allow them to continue monitoring for the remainder of 2011.

The project controls team utilized the EVA information to determine if overrun of budget was reasonable, if the request could be accommodated, and if so how much budget could reasonable be pulled forward. The following exerpt from project files demonstrates the EVA information that was used. The company name “ABC” will be used in this example for illustrative purposes (City of Edmonton, December 2011).

“The following provides information on ABC budget planning, assumptions and progress that have been used in the EVA.

- *In general, up to the end of September ABC tasks (Roads, Drainage, Landscape) have progressed faster then they have expended effort. Earned progress more than spent.*
- *Current ABC budget for 2011 accounted for about 27% percent of their budget, whereas the Construction Manager (CM) is on pace to complete about 50% of the construction work that is being monitored by ABC in 2011 (they had only planned to complete about 45%). This is in part due to the good weather (longer season) as well as pulling 105 Street civil work ahead.*
- *ABC assumed no road, drainage or landscaping work from December to February. But the CM, seems to be planning to continue some of this work anyway. This will account for more progress.*
- *By the end 2011 Roads, Drainage, and Civil progress will be progressed further than was originally planned and ABC budgets are showing some signs of underrun for the project as a whole if this construction pace continues.*
- *2012 budget will need to be re-distributed over the year to account for any work over the winter that was not originally planned for by ABC. This*

should not impact the 2012 budget which is currently about 47% of their total budget.

In short, its does make sense that ABC has consumed their 2011 budget a bit early due to the increased construction progress that has been made. A shift of some 2012 budget (to a maximum of about 5% of total budget) to November and December 2011 is reasonable from an EVA perspective."

This example demonstrates that the methodology of planning the engineering EVA based on the construction schedule and tracking progress based on related construction progress allowed for an objective and rational check on budget overruns and requests for budget re-allocations. These assumptions, especially during the design phase are often not documented or communicated. The EVA offered a formal structure to do this. This is a prime example of management with the lights on - as EVA is often described.

Year-end Reviews

A technique used to add a formal status review process was to hold yearend review meetings with the EOR Teams and the managers of all other accounts on the engineers WBS. In these reviews an EVA summary was prepared and discussed with the teams regardless of performance level. This gave each team an opportunity to see how they have been progressing versus the planned construction progress and how best to move forward for the next two construction seasons. The figure below (**Figure 35**) is an example of one of these yearend review reports.

2011 Earned Value Analysis - Drainage

Overview

The engineer's planned budget expenditures were based on the construction baseline schedule. If construction and procurement progress would have progressed as planned in the baseline schedule, the EOR Team would have been awarded 52% progress. Due to the actual construction and procurement progress, 54% progress is awarded to the end of Nov/11.

The EOR Team planned to spend 36% percent of the approved budget to end of November 2011. Actual percent spent was 55%.

Planned Progress	Actual Progress	Actual Budget Spent
36%	54%	55%

This results in a cumulative cost performance., CPI = 0.87. With this information, the forecast at completion is $49K over budget.

The following sections contain the summarized EVA results and calculations.

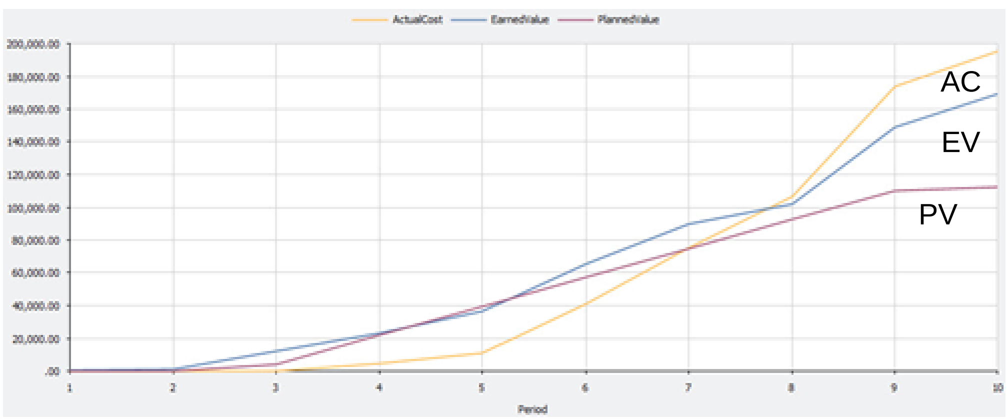

Figure 35 – Year end EVA status report. This example is for the Drainage EOR Team.

It became evident as the EVA summaries were reviewed and discussed, that although there were minor discrepancies in progress measurement identified, the results being shown were confirmed by the EOR teams and lengthy discussions were held as to the reasoning for the performance being where it was. Individual progress measurement calculations were tweaked slightly after the input from the EOR teams, but these reviews demonstrated that the overall approach for EVA on engineering work during construction was working effectively.

4.2.7 Reporting

The overall results of the EVA were communicated in the tables and figures shown below. These results were communicated on a monthly basis to the entire project team through the Monthly Progress Report. **Figure 36** depicts the overall EVA results. It shows the planned value over the life of the project (brown line), the earned value (yellow line), the actual costs (green line), the budget at completion (blue line), and the forecasted cost at completion (red line). From this figure, the project team can interpret that they have been generally earning more progress than they have been spending and that progress as a whole has been slightly ahead of the plan. However, in the last period, this trend has been changing significantly and actual costs and earned value and planned value seem to be converging. The trend of this convergence is the alarming part. The earned value is reducing and the actual cost is accelerating – a trend that will not end with success if continued. Perhaps the most interesting aspect of this figure is the forecast line. It started high at the beginning of the project and began a favourable trend downward for several months. However, since Period 5, the trend has shown a steadily increasing forecast. It is this trend that is the driver of concern on the project and sparked the major year-end reviews discussed previously. Noteworthy on this figure is that somewhat different picture the forecast gives versus the earned value. While the earned value is showing a healthy project (earned value above the plan and actual costs), the forecast is showing that the project is risking a serious overrun if current trend continue. This is due to the forecasting being included in schedule performance and being calculated as a summation of individual control account forecasts. This phenomenon is discussed in **Section 3.5** of this document where it is demonstrated that the traditional forecasting based on a summation of earned value and calculating forecasts independently at each level of the WBS tends to show an overly optimistic forecast versus summing individual forecasts to get the forecast for higher levels of the WBS.

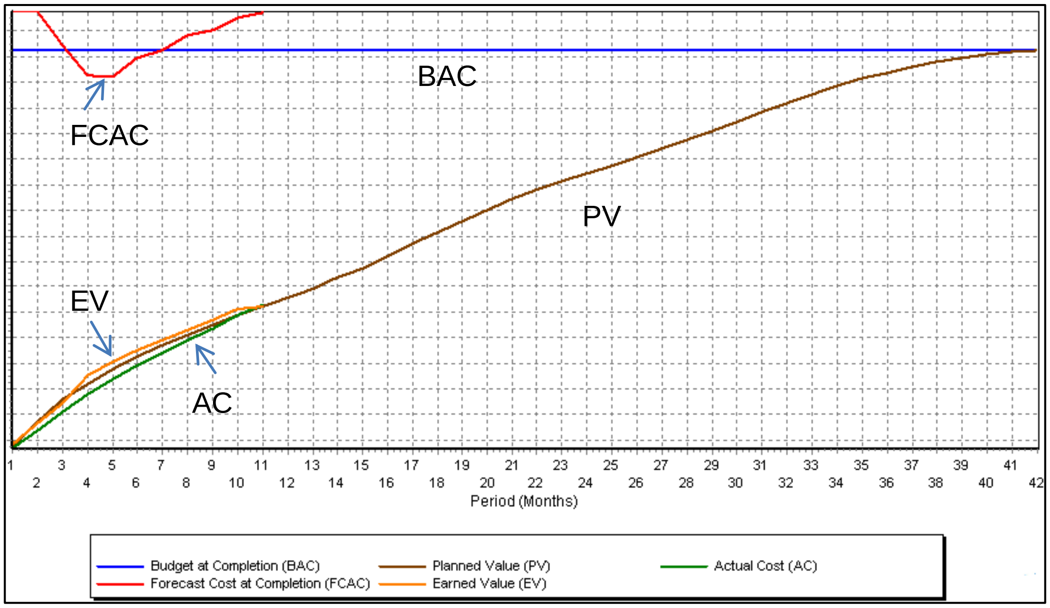

Figure 36 – Overall EVA chart used to communicate project status on a monthly basis. Note that the y-axis units have been removed for sensitivity purposes.

The next figure (**Figure 37**) is the Performance Indices figure. It communicates the cumulative cost and schedule performance trends overtime. This figure exposes where the project is headed and how stable the EVA calculations are at present. As can be seen the cost and schedule performance were relatively unstable for the first few periods of the project. After Period 4, however, the trends began to stabilize. The current trend is an unfavourable downward trend (especially for cost performance) and seems to be taking a turn for the worse at Period 11. The trends shown here confirm to the project team that changes must be made to how the project is currently progressing in order deliver a project on budget and schedule.

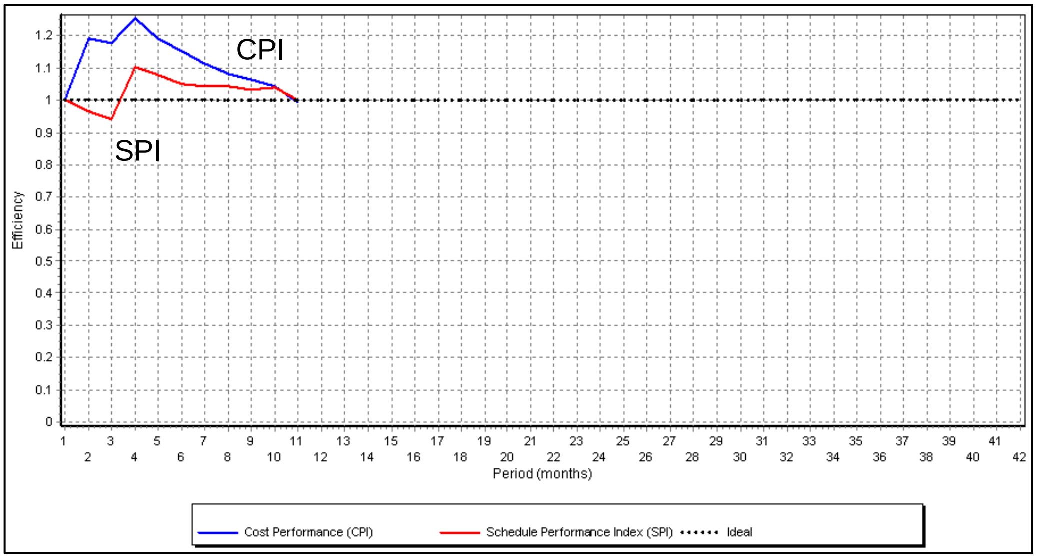

Figure 37 – Overall Performance Indices chart used to communicate the trends of cost and schedule performance on a monthly basis.

The detailed EVA information was communicated to the project team through the table shown in **Figure 38**. This table is shown as an example of the summary level EVA that was used. Down the left side were the various WBS accounts. The report was customized to include the project level, summary level or detailed control account level as required. For each account, several portions of information were communicated. The planned percent complete is compared to the earned percent complete and percent of budget spent in column 2,3,and 4. The remainder of EVA information is shown next including variances and period and cumulative performance indices. Then the forecast is displayed. The status indicators, as mentioned earlier, were used to focus attention on the items with poor performance. And the last column allowed and notes or comments to accompany the EVA results.

Task Name	Progress	Budget Spend	Planned Progress	BAC	Total Actual Cost	Period Actual Cost	CV	SV	CPI Per.	CPI Cumu.	SPI Per.	SPI Cumu.	FCAC	CVAC	Cost Status	Sched. Status
1000.01 Project Management	35.6%	33.6%	36.3%			$170.776	$154.616	-$57.248	1.17	1.06	1.30	0.98		$189.676		
1000.02 Project Controls	29.4%	32.1%	32.3%			$78.694	-$103.912	-$112.841	1.26	0.92	0.97	0.91		-$382.517		
1000.03 Management Support	20.8%	27.8%	25.7%			$42,871	-$149,291	-$104,489	0.68	0.75	0.78	0.81		-$668,334		
1000.04 Technical Support	17.3%	14.0%	15.9%			$14.438	$19.585	$8.297	3.64	1.24	3.86	1.09		$62.189		
1000.05 Construction Mgr - RFP	100.0%	100.0%	100.0%			$0	$0	$0	0.00	1.00	0.00	1.00		$0		
1000.06 Design Modifications	82.0%	70.7%	77.5%			$86,758	$416,931	$166,833	-4.71	1.16	-15.10	1.06		$508,453		
1000.07 Other Con. Contracts	100.0%	95.9%	100.0%			$0	$13,087	$0	0.00	1.04	0.00	1.00		$13,087		
1000.08 Procurement Packaging	85.0%	58.8%	100.0%			$0	$113.898	-$65.381	0.00	1.45	0.00	0.85		$134.053		
1000.10 Buildings	22.7%	16.7%	17.2%			$8.564	$36.111	$33.113	2.69	1.36	1.42	1.32		$159.247		
1000.11 Commissioning	21.7%	25.2%	27.5%			$42,505	-$92,042	-$154,298	0.84	0.86	0.68	0.79		-$424,721		
1000.12 Communication System	28.3%	32.1%	42.4%			-$19,243	-$31,549	-$116,206	0.00	0.88	1.81	0.67		-$111,070		
1000.13 Drainage	56.3%	67.3%	35.9%			$15.415	-$34.689	$63.769	0.45	0.84	0.00	1.57		-$61.822		
1000.14 Environmental	63.4%	63.4%	58.0%			$0	$0	$13.414	0.00	1.00	0.00	1.09		$0		
1000.15 Geotechnical	7.4%	7.4%	35.0%			$0	$0	-$55.289	0.00	1.00	0.00	0.21		$0		
1000.16 Heavy Civil	28.7%	46.9%	34.0%			$158,811	-$364,728	-$106,367	0.27	0.61	0.39	0.84		-$1,268,294		
1000.17 Landscape	8.5%	5.7%	3.4%			$170	$6,395	$11,593	8.42	1.49	0.00	2.50		$74,171		
1000.18 Roads	58.1%	22.8%	29.1%			$2,234	$267,250	$219,831	2.88	2.55	0.00	2.00		$460,305		
1000.19 ROW Electrical	24.5%	30.1%	37.8%			$3,143	-$10,479	-$25,037	0.74	0.81	0.25	0.65		-$42,807		
1000.21 Signals - CBTC	34.0%	46.0%	20.3%			$75.457	-$212.426	$243.535	0.47	0.74	0.89	1.68		-$624.782		
1000.23 Survey	100.0%	105.7%	85.9%			$4.087	-$2.648	$6.571	0.00	0.95	0.00	1.16		-$2.648		
1000.24 Trackwork	19.7%	29.6%	15.1%			$35.773	-$80.416	$37.300	0.13	0.67	0.48	1.30		-$407.618		
1000.25 Traction Power	13.8%	26.4%	19.4%			$39,779	-$83,347	-$37,497	0.22	0.52	0.42	0.71		-$604,712		

Figure 38 – Portion of the summary level EVA used to communicate results for all items on the Engineer’s WBS. Note that the budgets, forecasts, AC, and comments have been removed and the values shown are for illustrative purposes only).

The additional figure below (**Figure 39**) was used to communicate individual EVA results for each account on the WBS as needed.

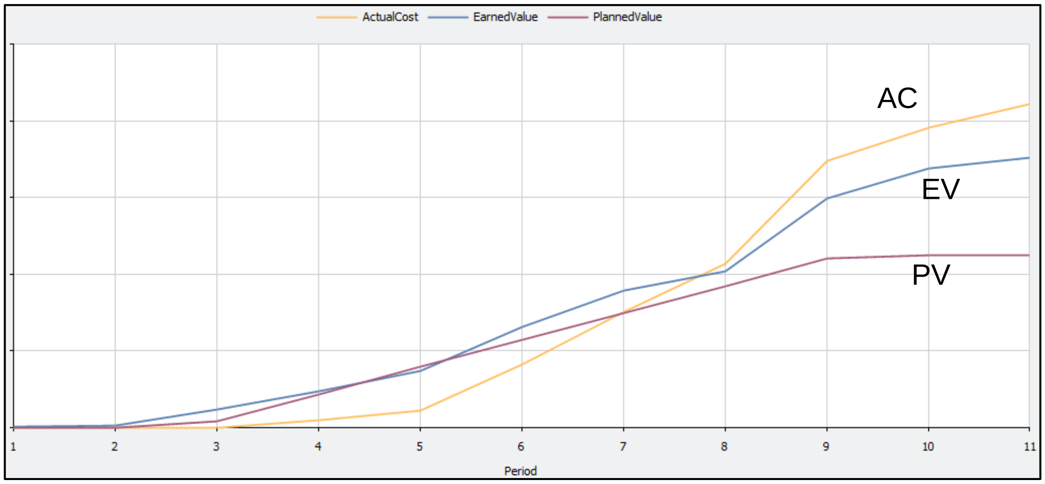

Figure 39 – Individual WBS account EVA figure. This figure was provided as needed to communicate EVA information for individual accounts when performance was deviating from the plan.

4.2.8 Summary Discussion

The application of the proposed approach to the construction phase demonstrates how engineering work can be successfully controlled in an environment where progress and schedule are solely dictated by external factors (construction progress). The superiority of the proposed approach over the existing controls for engineering work in construction is demonstrated through several examples and through the overall buy-in to the approach by the project team. The benefits that were realized:

- Existing method for planning engineering budgets did not account for and show adequate link to the construction schedule and was estimated based on crude assumptions of resource requirements. The EVM approach linked the budgets to construction activities and tracked changes to the engineering plan based on construction changes (e.g. when the construction schedule changed, the impact on the engineers work was quantified and adjusted).

- Progress measurement was non-existent in the existing controls. The EVM approach offered a method to quantify on a monthly basis the physical progress being made from each engineering package. Comparison of AC to physical progress exposed many important cost variances that would otherwise have gone unnoticed until too late to correct.
- Existing controls did not give any indication of projected cost outcomes. Budgets were assumed to be on track until they were overrun. The EVM approach provided forecasted of end results based on the latest performance information. These forecasts quantified and made real to the project team the impact of current cost and schedule performance and sparked corrective actions that otherwise would not have occurred.
- The proposed EVM approach brought a level of transparency to cost and schedule status that the existing controls could not offer.
- EVM reported were provided to various levels of detail depending on the audience and requirements. The project team became dependent on the monthly EVM reports to see current status and if corrective actions were having an impact.
- The owner was provided with a level of comfort that if something was going wrong, they would know, and corrective actions would be implemented and tracked.

Although the case study cannot conclude that the project completed on-time and on-budget, it does demonstrate the effectiveness of the proposed approach in practice. As a further proof of concept, the owner on this NLRT project has adopted the same EVM approach for controlling the engineering work during the next major LRT expansion – the Southeast the West Preliminary Design Project.

5 CONCLUSIONS

Engineering work typically accounts for 10% to 20% of capital project costs and the schedule of the design phase of a project can dictates the overall schedule, accounting for up to 50% of the delivery time. While research and industry have focussed on controlling construction work, control of the engineering effort on these projects warrants attention. Engineering work has been shown in many studies to be fraught with schedule overruns and cost increases (Barrie and Paulson, 1992; Chang, 2002; CMAA, 2004; Anderson & Tucker, 1994).

This research set out with the objective of improving the performance of capital projects by enhancing cost and schedule control of engineering work. The approach adapted proven EVM techniques used in construction, to the unique requirements of engineering work. By exposing the unique challenges with implementing EVM on engineering work, this research developed solutions that would allow it to be successfully used on engineering work in practice.

This research achieved its goal. Application of the proposed approach was undertaken on two major engineering projects to validate and refine the research in practice. The EVM techniques were first implemented as a shadow to the existing cost and schedule controls on the North LRT (NLRT) Detailed Design Project for the City of Edmonton. This study successfully demonstrated:

- that the EVM progress measurement offered reliable insight into project status and variances that were otherwise un-noticed by the existing controls;

- that while existing controls gave no indication of an issue, the forecasting offered by the proposed approach identified significant cost and schedule overruns in time to mitigate them;
- that early identification of budget underruns can be used to add valuable scope and risk reduction measures to significantly reduce project costs;
- that continual monitoring and reporting of cost and schedule performance of engineering work add transparency and accountability for everyone involved; and
- that the proposed approach was a key factor in bringing the project in on approved budget and schedule.

After this initial application and at the request of the project owner, the framework was extended to control the engineering work during the construction phase of the NLRT. From this second application, additional benefits and validation included:

- exposing weakness of existing budgeting techniques for engineering work in construction and offering a technique to integrate the plan and budget with the construction WBS/schedule;
- documenting key assumptions that allowed owner and engineer to justify budget overruns and underruns
- exposing actual progress of each engineering discipline and identifying variances that were otherwise undetected by existing controls; and
- when existing controls were limited to identifying budget overrun after they occurred, the forecasting showed owner and project team that the budget was on pace to be overrun by over $2,000,000 at completion, thus motivating major corrective actions years ahead of time.

Although, at the time of writing this the NLRT construction has only complete 1 of 3 years, the success of the EVM approach has earned the project teams respect and lead the owner to adopt the approach on the next major LRT expansion – the Southeast to West Preliminary Design Project.

5.1 Contributions

This research started out with identifying 10 key challenges with adapting the EVM approach to controlling engineering work. These challenges have been addressed throughout the document. The proposed solutions to these challenges comprise the major contributions of this research to industry and academia. An exhaustive list of this individual contributions is provided below for clarity, however, to summarize the primary contributions that this thesis has added to the state-of-the-art are:

- A method for breaking down and planning the entire engineering effort during design and construction based on measurable deliverables and expected levels of productivity.
- A method for tracking progress of engineering work based on pre-set milestones and weights.
- A method for forecasting unique to engineering work that is time dependent and tied to both cost and schedule performance.
- Techniques for prioritizing management attention and implementing corrective action.

The following provides a more detailed list of the challenges that were identified and a summary how they were overcome.

C1. Work-packaging, estimating, and scheduling to create an integrated cost and schedule baseline:

Solution offered:

- A structured approach to breaking down engineering work that facilitates planning and progress measurement based on measurable scope/deliverables.
- A technique for creating a fully integrated cost and schedule WBS that is flexible to the unique requirements of both structures and allows for ease of baseline adjustment when budget or schedule changes are made. Integrating cost and schedule structures has long been a barrier for EVM. EVM standards do not specify that the cost and schedule be built to the same structure, they merely state that these structures must be linked. This linking can be laborious and error ridden and does not allow for easy up-keep of the baseline when changes are made to cost or schedule. This research offers a solution to this issue.
- Recommendations to refine and re-plan budgets and schedules for the engineering effort after the proposal stage of a project. The traditional approach in industry is to use the proposal budgets and schedules to create the baseline, but this often does not reflect the realistic plan for the work. In order for EVM to be successful on engineering work, a refinement of this plan is necessary, and should involve the managers and engineers that will actually be conducting the work.

C2. Determining the proper distribution of effort over time for engineering tasks:

Solution offered:

- A technique for distributing budget over schedule for any work-package based on control period effort weightings. For any work-package, the level of effort expected in any one period is held as an effort weighting from 0 to 1 instead of a unit of measure (e.g. currency or labour hours). This allows for simple adjustment to the PVs for each period when changes are made to the budget for that work-package. This method also adds productivity and holiday impacts customized to each period of the project to further refine the distribution of effort.
- Preset distributions (uniform, front end loaded, back end loaded, center loaded, variable) for baseline cash-flow development (PVs) on engineering work or any other type of work that does not contain schedule and budget integration at a detailed activity level. The typical EVM approach is to use uniform distribution of the budget over the schedule for a given work-package to create the PVs. This technique works well when the work-package is relatively short or is consistent in nature. Engineering work is rarely broken down to enough detail to allow this assumption to hold. This technique to create the EVM baseline makes it more versatile and reduces the effort needed to implement the system.

C3. Tracking and incorporating cost and schedule changes into the EVM baseline:

Solution offered:

- Integrating baseline maintenance requirements into the existing change management processes on engineering projects (e.g. change order processes). Traditional forms of change management for engineering work do not provide enough detail to incorporate changes into the baseline and do not capture internal shifts to schedule or budget. Following the proposed approach to maintaining the baseline adds structure and consistency to the process. The recommendation is made to document all approved cost and schedule changes to control accounts and gather all required information to modify the EVM baseline in the process.
- A list of types of changes and processes for incorporating these changes (including retroactive changes that impact EVM in previous periods) into the EVM baseline. Change management is often cited as a critical EVM component. This research offers a summary of the different types of changes that can occur and directions on how to incorporate this change into the EVM baseline.
- A technique for handling retroactive changes or changes that apply to a particular timeframe of an existing control account. Traditional forms of incorporating changes into the EVM baseline do not readily account for the changes to existing control accounts when those change apply to specific periods of time (not over the entire control account schedule). The proposed approach offers a technique using control period weights that distributes only the budget change over the specified periods and then updates the control account period weights.

C4. Establishing practical methods for measuring progress that encapsulates the entire engineering effort

Solution offered:

- A progress measurement approach for the complete engineering effort in design, including: an improved progress measurement technique for management and other continuous type work; a deliverable weighting system to account for differing effort on one drawing versus the next without actually having to allocate specific budget effort to each drawing. The past approach for measuring design phase work focussed on drawing and specification deliverables only but did not measure progress on management or other supporting work.

C5. Planning engineering work and measuring progress during the construction phase

Solution offered:

- A technique for developing engineer's baseline during construction phase of a project that is linked to construction WBS, budget, and schedule. Engineering work in construction is highly dependent on the construction schedule and progress. This research proposes a structured technique to link engineering baseline development to the construction baseline and facilitates baseline up-keep when changes to the construction work occur.
- A progress measurement technique for tracking engineering work in construction that is integrated with construction and procurement progress and accounts for the effort that an engineering team must intrinsically dedicate resources to even if progress on site is not occurring.

No approach is offered in the reviewed literature for measuring engineering work during construction. Engineering work is difficult to measure during construction because there is a lack of clear deliverables that dictate progress. The approach is integrated with the baseline development approach discussed above, thus creating an integrated technique for controlling engineering work based on related construction work.

- A calibration technique to determine progress weighting for the different components of Design Discipline/EOR work during construction (general participation, procurement, and construction components of progress). Different disciplines require slightly different levels of effort for construction, procurement, and general participation. For example, a roadworks engineering discipline would likely require less effort in procurement than a communications engineering discipline would because there is significant amount of individual and specialized equipment required for communications work during construction. This technique projects the construction progress and than sets the engineer's progress weights so that progress will match the PVs as much as possible.

C6. Correctly allocating AC that are congruent with progress

Solution offered:

- Structuring the WBS based on design discipline to reduce errors in charging by internal staff.

- Recommendation for modifying WBS control accounts to allow division between different engineering firms on the project. This facilitates more accurate control. If a control account contains more than one firm, pin pointing which firms is contributing poor performance may be difficult and cumbersome.
- Proposal to use a charging protocol document that lays out very clearly which person or firm is to charge to which account.

C7. Prioritizing corrective actions for performance variances

Solution Offered:

- A technique for determining the criticality of forecasts at any level of the WBS with inclusion of management input, consistency of the forecast, and severity of the forecast in relation to project outcomes. Often forecasts are unreliable and fluctuate wildly from period to period. The techniques proposed allow the management team to determine which forecasts must be addressed and which are less critical.
- Use of dynamic status indicators for determining corrective action thresholds and focussing management attention. These color coded status indicators allow for larger variances at the beginning of the project and gradually close-in as the project progresses. This approach is linked to a system for determining severity of performance variances and triggering differing levels of action from the project team. This adds significantly to the efficiency of the project controls system.

C8. Forecasting that accounts for the relationship between cost and schedule unique to engineering work in design and construction phases

Solution offered:

- Dynamic forecasting approach based on stages of the project. The research draws from a vast field of research related to forecasting using EVM and combines various approaches to create a dynamic forecasting system using different forecasting equations at different stages of the project cycle. The approach provides recommendations for forecasting using schedule performance as a contributing factor.
- Proposed approach for forecasting at the project level as a sum of the individual forecasts. This is a contribution that addresses the tendency for the traditional form of forecasting at the project level to give overly optimistic results when based on rolled-up progress, not rolled up forecasts. This research purports that summing of individual forecasts at the lowest level (control account level) to get the project level forecast (or forecast at higher levels of the WBS) is a more accurate technique. This technique also demonstrates that the traditional form of progress roll-up to the project level based on weighted averages potentially gives a false percent complete when compare to the forecast based percent complete (actual costs to-date divided by forecasted costs at compeletion).
- A forecasting approach that is unique to engineering effort during construction. The engineering effort during construction is highly dependent on the construction progress and should be linked to this for forecasting. The difficulty is that construction work (especially none critical activities) are subject to excessive changes during construction

and this skews the engineer`s forecast. The proposed approach discusses how this link to construction schedule is accounted for in the progress measurement and forecasting for engineering work during construction.

C9. Gathering the required information to perform EVM in an accurate, efficient and timely manner

Solution offered:

- A technique to estimate AC in the absence of invoicing that is customized to engineering work was developed to help ensure that costs are always up-to-date with progress. This solves the issue evident in engineering work where invoicing at times does not match the progress measurement timing (e.g. late invoicing is much more common in consulting).
- A proven timeline to be used for monthly EVM including all required steps from invoicing and reporting progress, to preliminary results distribution and investigation, to corrective action development, reporting, and finally to meeting and decision making. This is especially an issue on major engineering projects where multiple consultants and sub-consultants have to feed into the EVM system. Literature does not touch on this.

C10. Reporting results visually and effectively to various levels of detail

Solution offered:

- A structured approach to reporting performance and determining corrective actions for engineering work in design and construction phases that leads to transparency with cost and schedule status.
- Highly visual system for reporting performance not only using the traditional figures but also adding color coded status indicators, color coded trending arrows, and budget size indictors on the summary EVA table. This provides at-a-glance EVA information at any level of detail and contributes to the efficiency of the recommended system.
- A technique for producing reports at differing levels of details as required, that builds off of existing literature and customizes to the engineering effort.

The overarching premise for each of these solutions was to enhance the efficiency of the project controls system. The effort required for controlling engineering work is under more scrutiny than that required for controlling construction work, because of the capital cost difference. Subsequently, the cost of implementing this form of project controls on engineering work should consume significantly less effort than implementing on construction work. To that end, this research emphasized efficient and practicable solutions to the challenges of implementing EVM on engineering work.

Owners and industry can greatly benefit from the research offered in this thesis. By utilizing this form of control for engineering work, the chances of project success are significantly increased. The City of Edmonton has adopted this form of project controls for its major projects and this raises the bar for other engineering work in the areas and industry.

5.2 Limitations and Potential for Future Research

Although the research has achieved what was set out to accomplish, there are still significant improvements to the process that can be made.

A work breakdown structure specific to the engineering effort has been proposed in this research, but it is by no means complete or exhaustive. Industry could benefit from development of a standardized breakdown of engineering work. This would improve application of project controls, estimating, scheduling, etc. and would also offer a means to gather historic data between projects.

The forecasting proposed in this research is solely based on static EVM techniques that exist in literature. Research and industry are moving more and more to the realm of simulation. Adopting a monte carlo approach to forecasting could help capture the uncertainties intrinsic in engineering and construction projects. Research could be conducted on how to plan and capture the EVM data in a distribution based format (e.g. measuring low, medium, and high progress values, shaping into distributions before conducting the EVM calculations).

Corrective actions is a major part of project controls. Research in the area of identifying and analyzing the root causes of performance variances on engineering work could create a framework to, in a sense, automate corrective action development and implementation. This would guide project managers on the most effective directions to take to correct poor performance and guide their projects to successful conclusion.

These list a few of the key areas that could use additional research in this subject matter, but this list is not exhaustive. There is always room for improvement and advancement

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