PROJECT DURATION FORECASTING:

A COMPARISON OF EARNED VALUE ANALYSIS

METHOD TO EARNED SCEHEDULE AS OF TIME DURATION

A Master Thesis

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By

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ABSTRACT

Earned Value Analysis (EVA) is a well- known planning and control management system that integrates cost, schedule and technical performance. It allows for the calculation of cost and schedule variances, performance indices as well as for the forecasting of project final cost and schedule duration. The Earned Value Analysis method provides timely assessment of project performance highlighting the need for eventual corrective action. EVA was originally developed for cost management and has not been widely used for forecasting project duration. EVA typically calculates the Schedule Efficiency through the Schedule Performance Index (SPI) based on budgeted cost and not on the time of work accomplished. Therefore, it may not accurately determine the time – base schedule efficiency, particularly for late completion projects, and it makes it difficult to correlate the final duration with project planned duration determined through Critical Path Method (CPM) network calculations. Earned Schedule (ES) is a method based on EVA but it develops a set of time dependent schedule indicators which perform consistently over the entire period of project performance and improve the accuracy of forecasting the duration of the project and its completion date.

The purpose of this study is to compare the classic EVA performance indicators with the time dependent ES performance indicators in order to help project managers to estimate and/or predict a more realistic and reliable time duration of project that can better correlate with CPM. It also explores how Building Information Modeling (BIM) simulation tools could be incorporated into EVA to visually communicate and quantify the timely phased physical progress during the development of project as opposed to the traditional use of cash flow analysis.

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Mumtaz A. Abdulahad

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Chapter 1 Introduction

Earned Value Analysis (EVA) was taken from industrial engineering in factories where planned standards and earned standard were linked primarily to labor hours (Lanner 2004). In the mid 1960’s,the United States Air force started setting standards to oversee Department of Defense (DoD) contractors performance. The resulting system was DoD Cost / Schedule Control System Criteria C/SCSC issued in 1991 revision which included 35 detailed criteria for performance reporting that were later reduced to 32 (Abba 1995), Abba 1999).

EVA has shown to be a reliable tool for monitoring project progress when sufficient information regarding the project work to be done can be linked to specific scope deliverables and to the organization’s resources needed to perform the work (Lanner PMP 2004). EVA also provides reliable performance measurement of time progress as early as the 15% percent completion point of a project (Fleming and Koppelman 2002).

However its ability to predict schedule delays has come into question as it does not take into account the time value of money (Fleming & Koppelman 2003 & 1994 C), which makes project managers less confident and depend on their intuitions to assess the final completion time of late completion projects.

The Earned Schedule (ES) is an extension of the EVA method. It is an emerging practice in project management (Lipke 2003), (Lipke 2012). It determines the time at which the Earned Value accrued should have been occurred according to the original plan and calculates the time variance in terms of time and not in terms of cost. It also focus significantly on monitoring and forecasting project schedule performance using the standard Earned Value Analysis (EVA) technique, i.e., performance indicators, Budgeted Cost of Work Scheduled ((BCWS), Budgeted Cost of Work Performed (BCWP), Actual Cost of Work Performed (ACWP), and Budget at Completion (BAC). This concept improves time metrics accuracy in latter periods of project performance and overcomes the major limitation of EVA for late completion projects by providing meaningful time metrics for the entire period of project performance.

Building Information Modeling (BIM) is an enabling technology that promotes collaboration among parties and allows to visualize in 3D different design options helping clients and designers to better understand different options. It can be used to check cost estimates by quantifying the material from 3D model and helping to detect the clashes of different building components. It can also be used to track the project milestones in phases to foresee the progress of project throughout construction. A 5D model combines the 3D view of the model plus its time and cost implications and explicitly displays dynamic correlation among the three variables scope – time and cost in clear visual fashion facilitating the understanding of the impact that each variable has on the other two as well as on the communication among the project participants.

Objectives of this Study

It is the purpose of this study to:

- Compare EV performance Indicators with time dependent ES Indicators to determine a more realistic time duration that can be correlated with CPM.

- Demonstrate that by using the ES concept, the project managers do not need to depend only upon their intuition to forecast the final duration of “late completion projects” when they can rely on a robust method for determining the entire time duration or earned schedule of project tasks that better correlate with CPM and stakeholders expectations.
- Explore how Building Information Modeling (BIM) simulation tools could be incorporated into EVA to visually communicate and quantify the timely phased physical progress during the development of project as opposed to the traditional use of cash flow analysis.

The above objectives are attained by conducting a exhaustive review of Earned Value Analysis (EVA), and Earned Schedule (ES) concepts and procedures and by developing a Case Study based on the design and construction of the recently built WPI Parking Garage with Rooftop Athletic fields. This case study compares the results generated by the use of EVA and ES and explores the use of BIM in conjunction with ES through the creation of 4D and 5D simulations.

Chapter 2. Earned Value Analysis

This study involves the utilization of Earned Value Analysis concept (EVA), which is a performance management tool that integrates cost, schedule and technical performance to facilitate graphic presentation of Schedule and Cost Performance compared to plan. (Lipke 2003), (Wilkens 1993). Before going deeply in the subject, the following definitions and meanings existing in Earned Value Analysis (EVA) terminology are introduced:

1. Earned Value Analysis (EVA): is a quantitative project management technique for evaluating project performance and predicting final project results, based on comparing the progress and budget of work packages to planned work and actual costs.
2. Earned Value Management (EVM): is a project management methodology for controlling a project which relies on measuring the performance of work using a Work Breakdown Structure (WBS) and includes an integrated schedule and budget based on the project WBS.
3. Earned Value Management System (EVMS): is the process, procedures, tools and templates used by an organization to conduct Earned Value Management (Lukas 2008).

The Earned Value Analysis (EVA) was developed as a tool to facilitate project control. It is used for determining a project's status with regards to cost and schedule. It uses cost variance and schedule variance to determine the amount of deviations from the plan as early as possible, so that enough time is made available for project managers to assess whether the deviation may have potential negative impact, and to take corrective actions. Moreover, it allows project managers to make inferences on the final effect of the project in terms of cost to and some extent, in terms of duration, by extrapolating from current trends (Brake 2006), (Czarnigowska 2008), (Rose 2011).

2.1 Earned Value Analysis Parameters

Earned Value Analysis parameters are used to track the progress of projects and to compare deviations (if any) against the planned performance also known as Budgeted Costs of Works Scheduled (BCWS) that both the contracted parties (owner and the contractor) have agreed upon in the contract. These parameters require definition of the following inputs or elements as follow:

At = Actual Time of work in progress at the reporting date.

PD = Planned Duration of the project Baseline (days, weeks, months, years).

t = Reporting Date

T'= Actual Completion Date.

Figure (1) below shows the general representation of how Earned Value Analysis (EVA) parameters cover the whole aspects of project performance and how they contribute to set mathematical relationship for each metric. This happens for any project regardless of its size and cost.

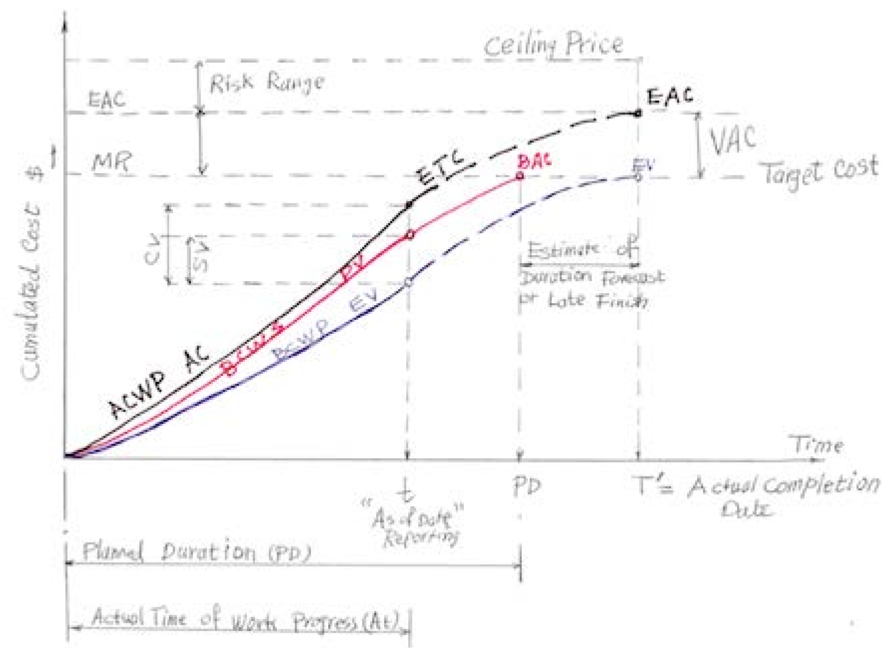


Figure 1 Earned Value Analysis Parameters

As one can see, the Earned Value Analysis concept mainly consists of three curves: Budgeted Costs of Works Scheduled (BCWS), which is the baseline for the analysis is a function that links cumulated planned costs with time of their time occurrence (PMBOK, 2008), (PMBOK 2013). It represents the sum of budgets for all work packages scheduled to be accomplished within a given time. This is calculated as

BCWS = Hourly Rate* total hours planned for any given time (t) *Equation 1*

Or, the cumulative summation of the cost of all time-related work packages. As shown in Equation (2) below

$$\text{BCWS} = \sum_{Start}^{Current} \textit{Time related} \text{ work packages (Material, Equipment \& Labor}$$ *Equation 2*

This curve (BCWS) is also known as Performance Management Baseline (PMB), which will be thoroughly explained in the following pages due to its significant value in determining the feasibility degree of Earned Value Analysis metrics in the management of projects. Budgeted Cost of Work Scheduled (BCWS) is sometimes defined as Planned Value (PV) curve, or sometimes called the “Baseline” or S-curve only. So,

$$BCWS = PV = PMB = S\text{- curve}$$

2.2 Establishing Performance Management Baseline (PMB)

The Work Breakdown Structure (WBS) is a deliverable-oriented grouping of project elements (granularity) that organize and defines the total scope of the project. Each descending hierarchical structure represents an increasing detailed definition of project work.

Figure (2) below displays the process of establishing PMB based on the WBS. It includes three main elements: definition of work, schedule the work, and allocation of budget which are derived from the Work Breakdown Structure (WBS). Therefore, costs, schedule and responsibilities are consistently associated to each of the tasks. For a large project, it will be a tedious task to calculate these elements manually, therefore one can rely on scheduling software like Microsoft Project, Primavera P6 that could be used to calculate and associate these three elements.

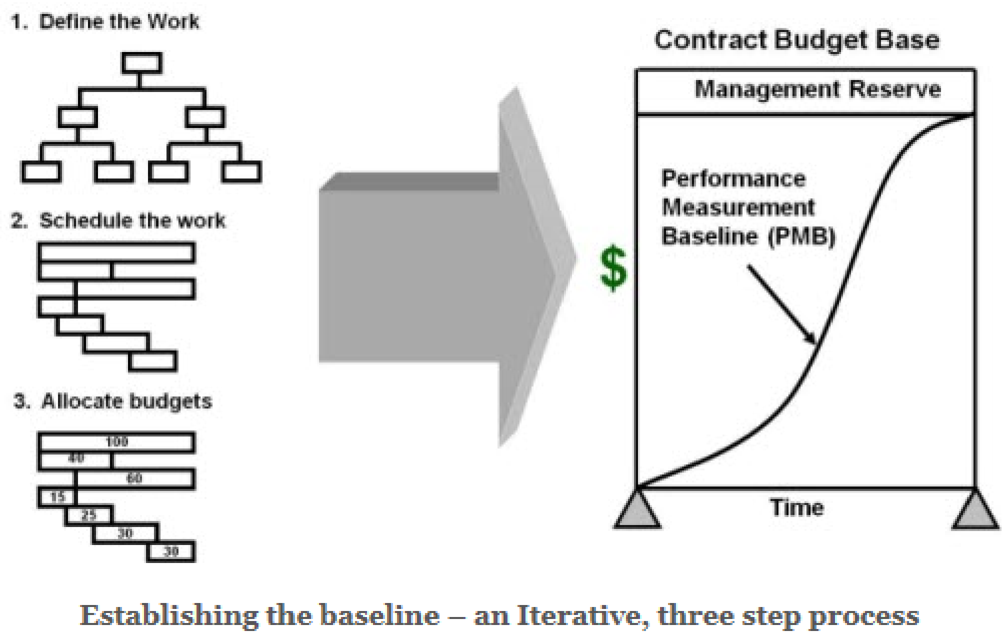


Figure 2 Formation of Baseline or S-curve.

Source: http://www.humphreys-assoc.com/evms/basic-concepts-earned-value-management-evm-ta-a-74.html

2.2.1 Performance Management Baseline Characteristics

The Performance Management Baseline has the following characteristics (EVMIG 2006):

1. It accurately represents only authorized work on the contract.
2. It includes a realistic network schedule baseline.
3. It includes a realistic time phased spread of budget/resources to the baseline schedule.

It is worth to mention that besides the above mentioned points, Building Information Modeling (BIM) tools can be used effectively in the creation of Performance Management Baseline due to the accurate quantification of project elements as well as other time saving functionalities such as clash detection, and coordinating ability for updating of last minute negotiation changes. These are significant factors which have contributed to make the Earned Value Analysis concept more rigorous and vital in controlling the project performance.

2.2.2 Performance Management Baseline Data Relationships

Figure (3) below shows the relationship between the “Work Breakdown Structure” (WBS representing the scope of work) and a time-phased schedule of work to be done with realistic cost estimates for each of the “Work Packages” in the project.

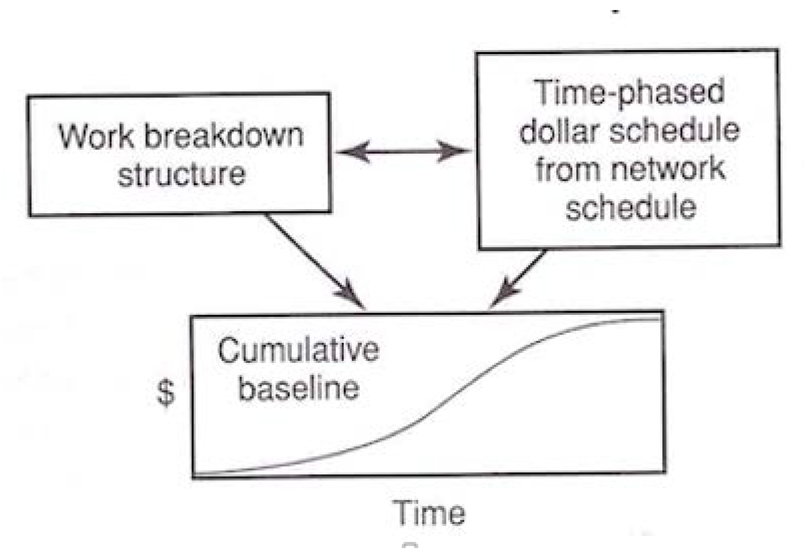


Figure 3 Performance Management Baseline (S-Curve) Data Relationships

Source: http://www.leaderelper.com/pdf-files/LCSI-EV6111-4-Hour-EarnedValue-KeySlides.pdf

As changes to the WBS, cost estimate and/or schedules are approved, the Baseline should be updated as shown in Figure (4), and performance is compared to the new Baseline.

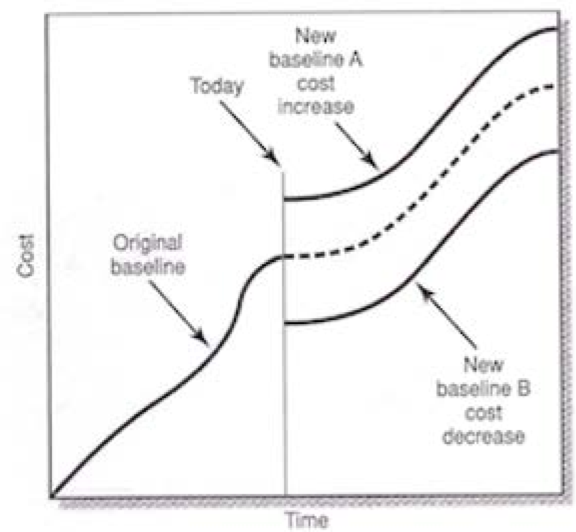


Figure 4 Performance Management Baseline updating (due to any changes)

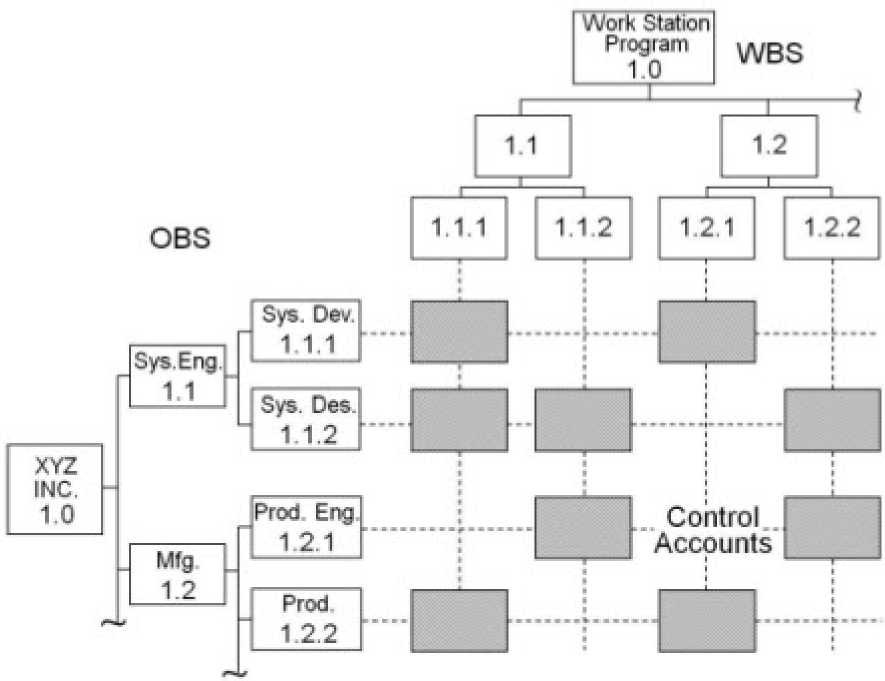
http://www.leaderhelper.com/pdf-files/LCSI-EV6111-4-Hour-EarnedValue-KeySlides.pdf

Updating starts from the effective time of change order approval (Fleming and Koppelman 1996).

The actual performance data must be collected periodically to effectively use the Performance Management Baseline (PMB) which is preferably built up using the Budgeted Cost of Work Schedule (BCWS) rather than Actual Cost of Work Performed (ACWP) (Christensen 1998). Because tracking progress through BCWP can provide an early warning about the deviation from the plan, then it could be made part of the risk management for whichever party (Owner, Contractor) takes the greatest cost risk and be alerted before the budgets are exhausted. Otherwise the benefit of Earned Value as an early warning for cost overruns is lost. This approach provides cost information, and help the Project Manager (PM) to seek solutions to maintain the successful continuation of the project in a timely fashion.

2.2.3 Control Accounts Plan (CAP)

Figure (5) below, shows a Management Control Diagram, known as the Control Accounts Plan (CAPs), where the management control is maintained through the (CAP). CAPs are used to measure the Earned Value at the most basic level of formation.



Intersection of the WBS and OBS establishes the control accounts

(

Figure 5 Points of Management Control Accounts (CAPs)

Source: www.humphreys-assoc.com) basic concepts of Earned Value Analysis

The elements that are necessary to create a Control Accounts Plan (CAPs) include :

1- Establishing the Scope of work (WBS).

   The Work Breakdown Structure (WBS) is a deliverable-oriented grouping of project elements that organizes and defines the total scope of the project. Each hierarchical structure represents an increasingly detailed definition of the project work.

2- Creating a Schedule of Activities.

By using an updated project management software planner such as Microsoft Project it is possible to create sequential series of interrelated activities.

3- Establishing a Budgeted Cost of activities.

This could be done with the help of previous historical documents of similar activities that the firm has accomplished.

4- Assigning a Team Leader to manage the planning and lifecycle of project.

This could be done through a Responsibility Assignment Matrix (RAM) which depicts the relationship between Work Breakdown Structure (WBS) elements and Organization Breakdown Structure (OBS) elements that assigned responsibility for ensuring accomplishment of the project work.

5- Creating large homogenous WBS levels.

6- Determine multiple functions integrated with WBS.

2.3 Objectives of creating an Organization Breakdown Structure

An Organizational Breakdown Structure (OBS) is created in order to establish a clear picture of the total project work scope, and to assign responsibilities to the right people. The organizational process includes the following:

1. Create a WBS by decomposing the work into manageable work packages.
2. Define the Organization Breakdown Structure.
3. Assign a single work package to single party in the Organizational Breakdown Structure.
4. Create Control Account Plans (CAPs) as indicated, implies to create the controlling aspects for interrelated Schedule and Budget. (Humphreys 2001).

Figure (6) below shows how “Work Packages” with their associated detailed information for planning and tracking are consolidated by period to create an S- Curve / Baseline Schedule against which the amount of Budgeted Cost of Work Performed (BCWP) is expected to be completed each planning period.

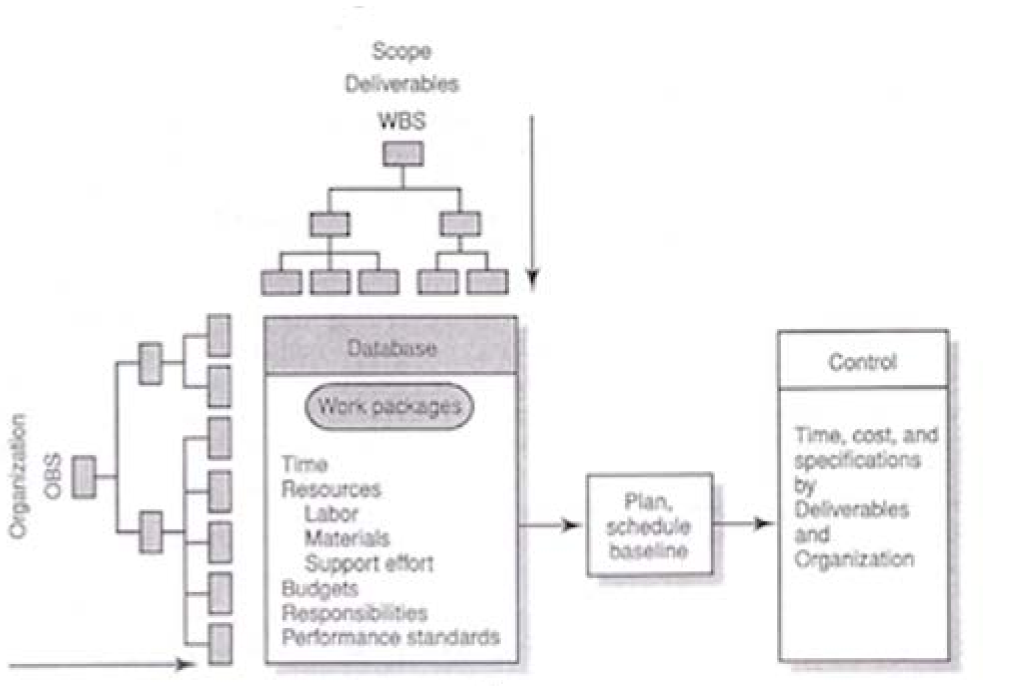


Figure 6 Project Management Baseline formation From Planning to Control

Source: http://www.humphreys-assoc.com/evms/basic-concepts-earned-value-management-evm-ta-a74.html

2.4 Critical Path Method (CPM)

The Critical Path Method is a network analysis technique used to predict project duration by analyzing which sequence of activities (which path) has the least amount of scheduling flexibility the least amount of Total Float or the amount of time that a task in a project network can be delayed without causing a delay to subsequent tasks thus delaying project completion date. The Critical Path is also defined as the largest path duration of interrelated sequenced activities on project network of a program which is the BCWS Planned Duration (PD) itself also.

Total Float can be measured by subtracting the early dates from late dates of path completion.

$$T.F = L\,F_{\text{of current task}} - E\,F_{\text{of current task}}$$

The Free Float (F.F) is the amount of time that an activity can be delayed without delaying the early start of its successor activity.

$$F.F = ES_{\text{next task}} - EF_{\text{current task}}$$

The following are some of the essential EVA parameters:

Budget At Completion (BAC) is the total planned cumulative cost of all work packages in the project, it equals BCWS at Planned Duration (PD). It could also be defined as a cumulative summation of a specific dollar of work scope (tasks) of a BCWS when all work packages have been phased, the cumulative BCWS = BAC. It could also be the "Total Budget" allocated to the project, plotted over time, say like periods of reporting (weekly, monthly, yearly…etc.). BAC is used to compute the following EVA metrics:

- "Estimate At Completion" (EAC)
- To complete the Cost Index (TCPI)
- To Complete The Schedule Index (TSPI).

BAC **is** calculated using the following formulas:

BAC = (BCWS Efforts-hrs.)* (hourly Rate)

Equation 3

It is also calculated as the Cumulative Summation of all Time-phased Budgets of work packages / BCWS, where work packages incorporate direct cost of construction material, and equipment only.

$$\text{BAC} = \sum_{Start}^{Current} \text{PV (Completed)}$$

Equation 4

In addition to Budgeted Cost of Work Schedule (BCWS), there is generally an amount of Management Reserve (MR), which is a portion of the total program budget not allocated to specific work packages and withheld for management control process. Thus, Budget At Completion (BAC) consists of the BCWS plus all the Management Reserve (MR) amount**.**

Budgeted Cost of Work Performed (BCWP) or Earned Value (EV) (PMBOK 2008). It is a measure of physical progress of work expressed by cumulated planned cost of work actually done related to the date of reporting. It is also the total cost of work completed/performed as of reporting date. It can also be seen as the sum of completed work packages and completed portions of open work packages. Essentially it is the value of work earned.

This is calculated as:

*BCWP = Budget At completion * % Complete*

Equation 5

Where % Completed or PC = (Budgeted units) - (Units to complete) / Budgeted units.

It is worth to mention that on early completion or on time completion (on budget) the Budgeted cost of work performed (BCWP) = (BCWS) = BAC.

Actual Cost of Work Performed (ACWP) or Actual Cost (AC), (PMBOK 2008) is the cumulative actual cost of the work completed as of reported date. It is also the amount of money (cost) or resources expended in order to accomplish the amount of work achieved for the reporting period.

ACWP = (Hourly Rate) * (Total hours spent)

Equation 6

ACWP is the cumulative summation of actual cost spent for material, equipment and labor for accomplished work over time.

2.5 Measuring Options of Earned Value Analysis

Each control account manifests at a work package level the overall project plan for activities to produce project deliverables (i.e., the schedule), the use of resources (i.e., the resource and procurement plans), and the commitment and expenditure of funds (i.e., the cost budget). Physical progress against each of these plan elements is measured to support Earned Value Analysis and forecasting.

Some options might be adopted are: (Lanners 2004)

1. Milestones with weighted values. (These can be complex to set up). The weighted milestone technique divides the work to be completed into segments, each ending with an observable milestone; it then assigns a value to the achievement of each milestone. The weighted milestone technique is more suitable for longer duration tasks having intermediate, tangible outcomes. (limits over-estimating)
2. Fixed Formula (25/75; 50/50; 75/25), A typical example of fixed formula is the 50/50 technique. With this method, 50% of the work is credited as complete for the

measurement period in which the work begins, regardless of how much work has actually been accomplished. The remaining 50% is credited when the work is completed. Other variations of the fixed formula method include 25/75 and 0/100. Fixed formula techniques are most effectively used on small, short-duration tasks.

3. Percent-Complete Estimate: the percent complete technique is among the simplest and easiest, but can be the most subjective of the Earned Value measurement techniques if there are no objective indicators to back it up. This is the case when, at each measurement period, the responsible worker or manager makes an estimate of the percentage of the work complete. These estimates are usually for the cumulative progress made against the plan for each task. However, if there are objective indicators that can be used to arrive at the percent complete (for example, number of units of product completed divided by the total number of units to be completed), then this can be a more useful technique. (Commonly used)
4. Percent-complete with Milestones Gate: this method is satisfactory if based on objective metrics.
5. Equivalent Units: One man-hour works for eight hours is equivalent to eight men working for one hour. Or converting the units of measurement used to quantify different elements of work package into one "equivalent" unit. For example Tons of Steel.
6. Earned Standards or Units Complete: It is good for longer work packages are being done.
7. Apportioned Relationship to Discrete Work. (i.e., "burden") for work that is not easily measured like "soft" costs, but which is proportional to a measurable effort. Avoid

using an apportioned measure for a large value work package where the basis for the apportioning is a significantly smaller value work package.

8. Level of Efforts (LOE). Work of general or supportive nature (such as coordination, follow up, liaison) that doesn't result in a definitive end product or outcome. It is not recommended, as it does not measure the task schedule performance (SV), is based on setting the Budgeted Cost of Work Performed (BCWP) equal to the Budgeted Cost of Work Schedule (BCWS) for each performance reporting period. Thus, the schedule performance (SV) is always zero. It does, however, provide early cost variance (CV) visibility to a potential overrun on the (LOE) tasks. Level of Efforts (LOE) is applicable for management, measuring Earned Value for the Management Reserve (MR), and administrative tasks as being unmeasurable tasks. Accordingly, some authors advise not to use it as much as possible as it distort the overall project's earned value as portion of the Earned Value derived from (LOE) work packages grow relative to the total project planned value.

Recommended usage of options:

a. Options from No. 1 to No. 4 are typically used for non-recurring tasks.
b. Options from No. 5 to No. 6 are used for either non-recurring or recurring tasks.
c. Option No. 7 could be used for any points from 1 to 6.
d. Option No. 8 is not recommended for use.

The guidelines for selecting of BCWP Measurement Techniques are outlined in the following Table (1) below.

Product of Work	Duration of Work Effort	
	1-3 Measurement Periods	> 3 Measurement Periods
Tangible	Fixed formula	Weighted Milestone, Percent Complete
Intangible	Apportioned Effort, Level of effort.	

Table 1 EV Measurement Techniques

2.6 Project Status Indicators (Metrics),

Earned Value Analysis has large number of metrics used to track and monitor the progress of work in the project, the most important and basic metrics are listed as follows:

2.6.1 PP – Percentage Planned.

It is the percentage of work which was planned to be completed by the reporting date. This is calculated using the following formula:

PP = BCWS/BAC*100

The range of this metric for 0 ~ 100%

2.6.2 PA – Percentage Actual.

It is the percentage of work was actually completed by the reporting date, sometimes defined as Percent Spent. This is calculated using the following formula:

PA = ACWP/BAC x 100

The range of this metric is from 0 ~ ∞. (due to cost overrun in late completion project).

2.6.3 PC – Percentage Complete

It is the percent of work earned by the work completed as of reporting date.

This is calculated using the following formula

PC = BCWP/BAC x 100

The range of this metric is from 0 ~ 100%.

Cost Variance (CV) is a very important factor (Metric) to measure project performance. Cost Variance indicates how much over or under budget the project is by the reporting date. Cost Variance represents the gap between Budgeted Cost of Work Performed (BCWP) versus Actual Cost incurred (ACWP) as of reported date.

Cost Variance can be calculated using the following formula,

CV = BCWP – ACWP

Equation 7

The formula above gives the variance in terms of cost which indicates how less or how much more has been used to complete the work as of date.

- Positive Cost Variance indicates the project is under the budget.
- Negative Cost Variance indicates the project is over budget.

Cost Variance Percentage (CV%) it is an indicator of cost that shows how much over or under budget the project is in terms of percentage. Cost Variance Percentage can be calculated using the following formula:

CV % = (BCWP – ACWP) / BCWP (as of reporting date) x 100

Equation 8

The above equation determines the variance (gap) in terms of percentage which will indicate how much less or how much more money has been used to complete the work as planned in terms of percentage.

- Positive variance %, Indicates %, under budget,
- Negative %, Indicates % over budget.

Cost Performance Indicator (CPI). It is an Index value showing the efficiency of utilizing the "resources" on the project. Cost Performance Index (metric) can be calculated using the following formula:

CPI = BCWP/ACWP

Equation 9

It measures the efficiency of the project team in utilizing the resources allocated to the project team, and can be used to predict the final range of costs.

- CPI value above (1) indicates efficiency in utilizing the resources allocated to the project.

- CPI value below (1) indicates deficiency in utilizing the resources allocated to the project. So, CPI is a metric of a project team efficiency in utilizing the resource allocated for the project as of reported date.

2.6.4 To Complete Cost Performance Indicator (TCPI)

To Complete Performance Index (Indicator): It is a forecasting indicator or metric showing the efficiency at which the resources on the project should be used for the remainder of the work to meet the planned Budget At Completion (BAC). Or is a portion between the remaining work and the money left from the Budget. (Czarnigowska 2008).

This metric can be calculated using the following formula.

TPCI = (BAC – BCWP) / (BAC- ACWP)

- TCPI value above (1) indicates utilizing of the project team resources for the remainder of the project can be stringent.
- TCPI value less under (1) indicates utilization of the project team resources for the remainder of the project can be lenient.

2.6.5 Schedule Variance (SV)

Schedule Variance indicates how much time in terms of cost/ volume of the work (i.e. $ 1.0 = one unit volume of work) is the project ahead or behind schedule. It shows the gap between the work performed versus the planned work. Schedule variance can be calculated as using the following formula.

Schedule Variance (SV) = BCWP - BCWS

Schedule Variance Percentage (SV%). Indicates how much time ahead or behind schedule the project is in terms of percentage of time. It can be calculated using the following formula

$$SV\% = \frac{\text{Schedule variance (SV)}}{\text{BCWS as of reported date}} * 100$$

Equation 10

So, it is an indicator (metric) of time consumed for the accomplished work.

The aforesaid formula gives the variance in terms of monetary value as percentage, which will indicate how much percentage of work (cost) is yet to be completed as per the schedule or how much percentage of work has been completed over and above the scheduled cost.

- Positive variance %, indicates % ahead of schedule
- Negative variance %, indicates % behind the schedule

2.6.6 Schedule Performance Indicator (SPI).

Schedule Performance Indicator (SPI). It is an Index showing the efficiency of the "time" utilized on the project. Schedule Performance Indicator can be calculated using the following formula,

SPI = BCWP / BCWS

The formula above shows efficiency of the project team in utilizing the time allocated for the project. And can be used to assess how much work has been accomplished to date?

- SPI value above (1) indicates the project team is efficiently in utilizing the time allocated to the project.
- SPI value below (1) indicates the project team is not efficient in utilizing the time allocated to the project.
- SPI ratio equal (1) indicates the project team efficiency of time is as planned.

2.6.7 To Complete Schedule Performance Index (Indicator) (TSPI)

To Complete Schedule Performance Index, is a forecasting metric showing the efficiency at which the remaining time on the project should be utilized. This can be calculated using the following formula

TSPI = [BAC - BCWP] / [BAC - BCWS]

The formula mentioned above gives the efficiency at which the resources should be utilized the "remaining time" allocated for the project.

- TSPI value below (1) indicates project team can be lenient in utilizing the remaining time allocated to the project.
- TSPI value above (1) indicates project team needs to work harder in utilizing the remaining time allocated to the project.

The following prediction table (2) provides information concerning whether to attempt corrective action or negotiate a change with the customer.

TSPI	Predicted action
Less or equal 1	Achievable
More than 1.1	Non-achievable

Table 2 Prediction Table for meeting the budget and planned time.

2.6.8 Estimate To Complete (ETC)

Estimate To Complete (ETC), is the estimated cost/funds required to complete the remainder of the project (work) at any point in time. This indicator is calculated and applied when the past estimating assumption due to program halt became invalid and a need for fresh estimates arise. Estimate To Complete (ETC) is used to complete the Estimate At Completion (EAC). ETC is determined using the following formula:

ETC= BAC – ACWP

Where, ACWP is the actual cost to date and BAC is the budget at completion.

ETC is also the difference between estimate at completion (EAC) and Actual Cost of Work Performed (ACWP). This is the estimated additional cost/funds required to complete the remaining work on the task (s) from any given time.

2.6.9 Estimate At Completion (EAC)

Estimate At Completion (EAC), is a forecast defining the most likely total estimated cost & time based on project performance and risk quantification. At the start of the project, BAC and EAC will be equal. EAC will vary from BAC only when the ACWP vary from the BCWS (Nagrecha 2002). Moreover, it is observed that one of the more beneficial aspects of Earned Value concept is its ability to provide an independent forecast for the total funds required at the end of the project (Fleming & Koppelman 1994C).

EAC is the cost allocated to the work to date plus the Estimated Cost to Complete for authorized work remaining (Nguyen 1993). It is observed that the Estimate At Completion (EAC), is an important number and is very controversial, largely because there is literally an infinite number of possible EAC formulas (Christensen 1998). During a project, the cost control process focuses on cost overruns, of which there are two kinds:

1. Current Cost Overrun being presently experience (as of date), i.e., cost variance.

2. Forecasted Cost Overrun at completion, based on EAC.

These two kinds are shown in Fig (7) below

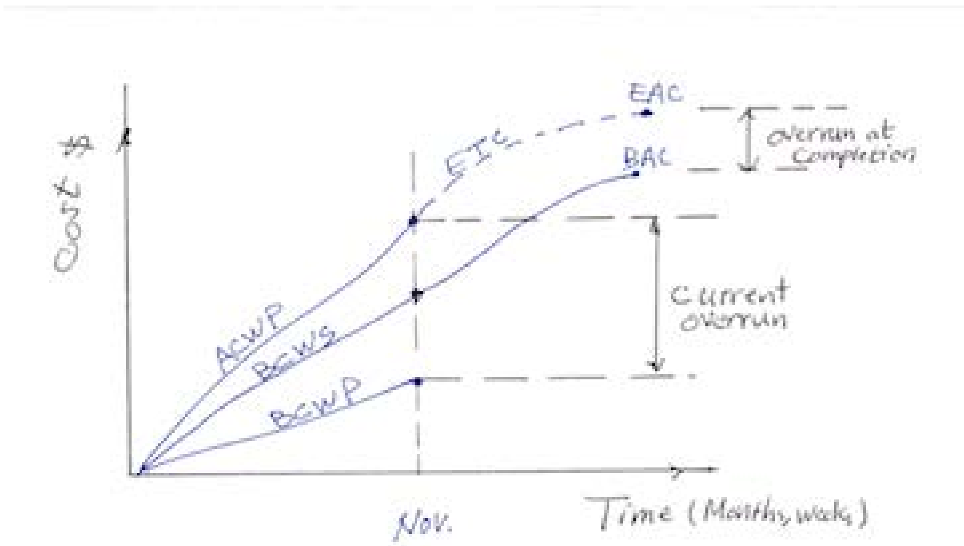


Figure 7 current overrun and overrun at completion

Therefore at any point of time in the project's development, there is always a need to forecast cost at completion. This information is often requested from project managers by anxious senior management and is vital to the project cash flow, the viability of project, and sometimes whether to cancel the project after it has started (Harrison 1981). It is worth noting that at the end of the project, BCWP equals BCWS and cost variance equals the final actual overrun, provided the scope does not change (see Figure 8 below)

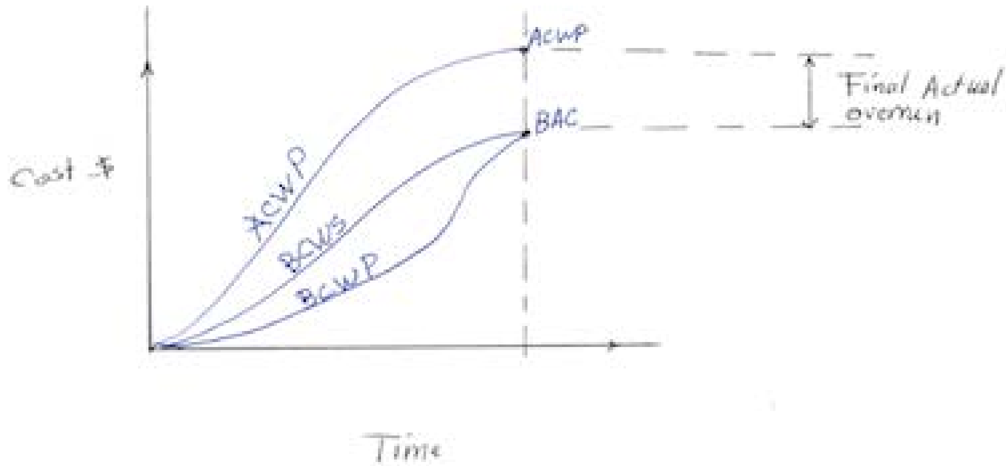


Figure 8 BCWP=BCWS At completion and cost variance equals final Actual Overrun.

Because the forecasting of ETC cannot be done with 100% certainty, this value can be calculated in different ways, all of them are variations of EAC. The following provide several different approaches to determine EAC:

- EAC = Actuals to date plus a new estimate for all remaining work or

EAC = ACWP + New ETC

This approach is most often used when past performance shows that the original estimating assumptions were fundamentally flawed or they are no longer relevant to a change in conditions.

- EAC= Actual to date plus remaining budget:

EAC = ACWP + (BAC - EV) (AACE, 1992)

This approach is most often used when current variance are seen as "Typical" and the project management team expectations are that similar variances will "not" occur in future.

- EAC = Actuals to date plus the remaining budget modified by a performance factor (PF) often the Cumulative Cost Performance Index (CPI). This approach is most often used when current variances are seen as "typical" of future variances (Turner 1993), (Fleming & Koppelman 1996).

$$EAC = ACWP + (BAC - BCWP) / CPI_{cum}. \text{ to date}$$

- EAC = Budget At Completion (BAC) modified by a performance factor, cumulative Cost Performance Index (CPI) (AACE 1992)

$$EAC = BAC / CPI_{cum} \text{ to date.}$$

This approach is often used when no variance from BAC has occurred or when future cost performance will be the same as all past cost performance (measure of lower bound).

- When future cost performance will be the same as the last three measurement periods (i j k), EAC can be calculated as follow:

$$EAC = ACWP + [(BAC - BCWP) / [(BCWPi + BCWP_j + BCWP_k) / (ACWPi + ACWPj + ACWP_k)]$$

- When future cost performance will be influenced additionally by past schedule performance, EAC can be calculated as follow:

$$EAC = ACWP + [(BAC – BCWP) / (CPI * SPI)] \quad \text{measure of upper bound}$$

- When future cost performance will be influenced jointly in same proportion by both indices. The following formula is most suitable (PMI - Practice Standard for Earned Value Management).

$$EAC = ACWP + [(BAC - BCWP) / (0.8\ CPI + 0.2\ SPI)]$$

The other EAC_t is the Estimated Finish Time or sometimes called "Actual Completion" as shown in fig (9) where the suffix (t) represents the time duration expected to complete the project. This Indicator is calculated by the following formula,

$$EAC_t = BAC / SPI / BAC / PD = PD / SPI$$

Where PD is the planned duration of the project.

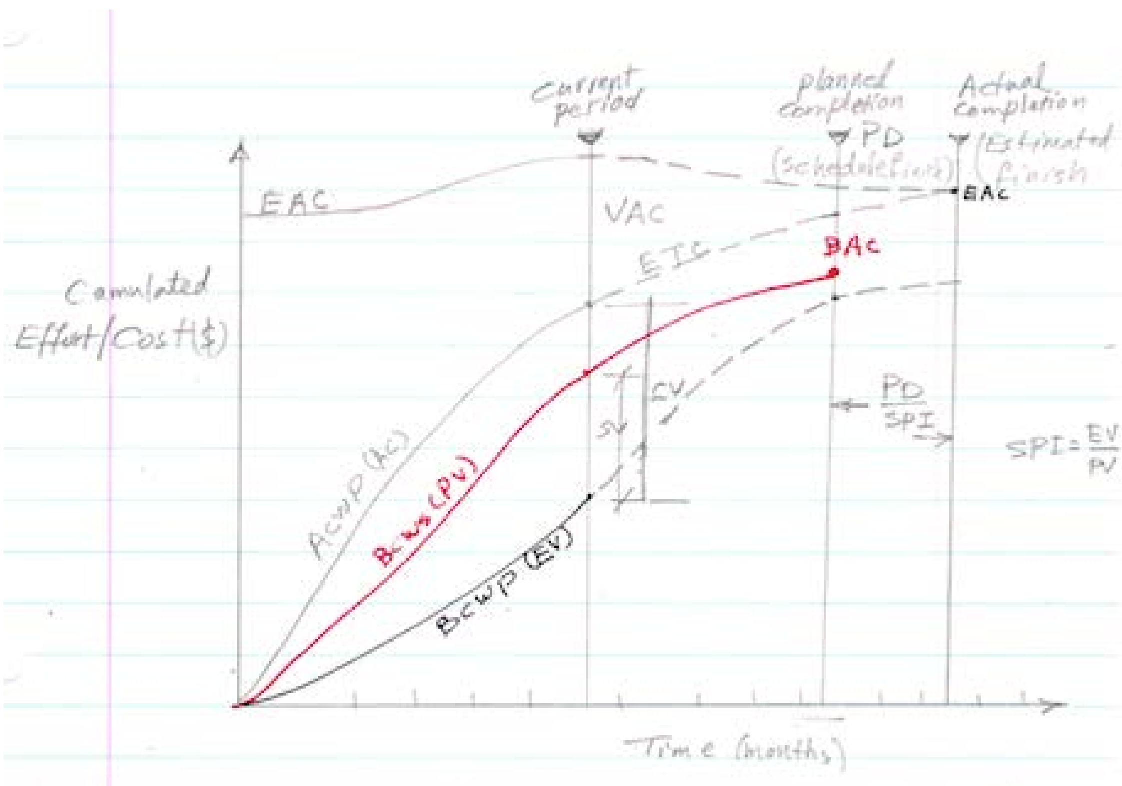


Figure 9 Time Basics Framework for EVA

However this method generates a fairly rough estimate and must always be compared with the statistics reflected by the time based schedule method such as Critical Path Method (CPM). (Fleming and Koppelman, 2009).

2.7 Variance At Completion (VAC).

This is another important metric in Earned Value Analysis Control System, which is defined as the difference between what the total job is supposed to cost,i.e., BAC, and what the total job is now expected to cost. This matric is calculated using the following formula (Refer to Figure 1).

$$VAC = BAC - EAC$$

The importance of this metric as a Control System for contractor(s) and owner(s) can be better understood by looking at how the positive or negative consequences on VAC impact each party as follows.

<u>Variation at completion (VAC) vs. Contractor loss on fixed price lump sum contract.</u>

If VAC is positive:

EAC < BAC → Under run budget → Contractor gain

If VAC is Negative:

EAC > BAC → Share area → Contractor Partial loss

EAC> Ceiling → Over run → Contractor loss 100%

Some practical recommendation for the owner can be derived from the calculation of EAC metric.

a) The owner should develop top level EAC for comparison

b) The owner will limit progress payment if EAC is greater than ceiling price.

c) The owner needs forecast of fund requirement. (Christensen, 1993).

Actual performance at 15% complete point can be used to predict final performance (Fleming and Koppelman 1999). Thus when the EAC and VAC results are substantially different from contractor's estimate BAC more than likely the project manager (PM) may question the discrepancy.

The Project Manager (PM) can also use the Independent Estimate At Completion IEAC or Estimate At Completion EAC to justify continuation of the project for upper management by the EAC & VAC for reaching implications (Lipke, 2012). Table 3 below provides a summary of Earned Value Analysis Terms

Term	Variable(Metric)	Description
PV (BCWS)	Planned Value	What is the estimated value of the work planned to be done.
EV (BCWP)	Earned Value	What is the estimated value of the work actually accomplished?
AC (ACWP)	Actual Cost	What is the actual cost incurred?
BAC	Budget at Completion	How much did you BUDGET for the TOTAL JOB?
EAC	Estimate at Completion	What do we currently expect the TOTAL project to cost?
ETC	Estimate to Complete	From this point on, how much MORE do we expect it to cost to finish the job?
VAC	Variance at Completion	How much over or under budget do we expect to be?

Table 3 Earned Value Analysis Terms.

Table 4 summarizes Earned Value Analysis Formulas and their interpretation

Name	Formula	Interpretation
Cost Variance (CV)	EV – AC	NEGATIVE is over budget, POSITIVE is under budget.
Schedule Variance (SV)	EV – PV	NEGATIVE is behind schedule, POSITIVE is ahead of schedule
Cost Performance Index (CPI)	EV/AC	I am {only} getting ____ cents out of every $1.
Schedule Performance Index (SPI)	EV/PV	I am {only} progressing at ____% of the rate originally planned.
Estimate At Completion (EAC) **Note:** There are many ways to calculate EAC	BAC/ CPI AC+ETC AC+BAC=EV (BAC-EV)/CPI	As of now how much do we expect the total project to cost $_____. □□ Used if no variance from the BAC have occurred and give lower boundary. □□ Actual plus a new estimate for remaining work. Used when original estimate was fundamentally flawed. □□ Actual to date plus remaining budget. Used when current variances are atypical. □□ Actual to date plus remaining budget modified by performance. when current variances are typical
Estimate To Complete (ETC)	EAC- AC	How much more will the project cost?
Variance At Completion (VAC)	BAC - EAC	How much over budget will we be at the end of the project?

Table 4 Earned Value Analysis Formulas

After exploring and discussing the Earned Value Analysis terms and metrics, Figure (10) shows how the EVA metrics relationships are set to form a framework.

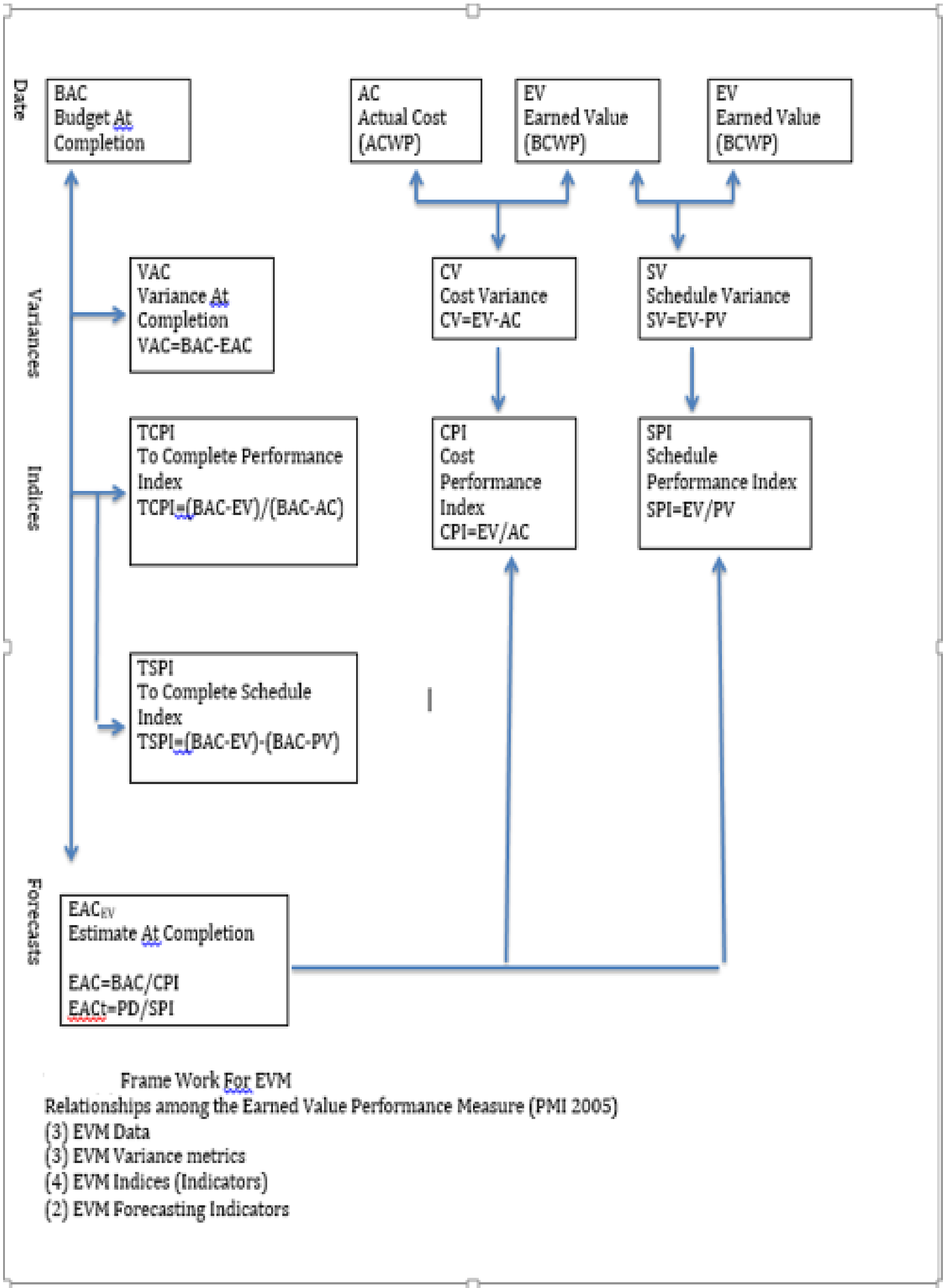


Figure 10 Framework of Earned Value Analysis

Table (5) shows “at-a-glance” what EVA performance measures indicate about a project in regard to its planned work schedule and resource budget.

Performance measures		**SV & SPI**		
		> 0 & >1.0	(=)o & (=)1.0	< 0 & < 1.0
CV & CPI	> 0 & >1.0	Ahead of schedule ; under budget	On schedule ; under budget	Behind schedule; under budget
	(=)o & (=)1.0	Ahead of schedule ; on budget	On schedule ; on budget	Behind schedule ; on budget
	< 0 & < 1.0	Ahead of schedule ; over budget	On schedule; over budget	Behind schedule; over budget

Table 5 Interpretation of Basic EVA Performance Measures

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Figure (11) below shows the relation between program management elements and general program components

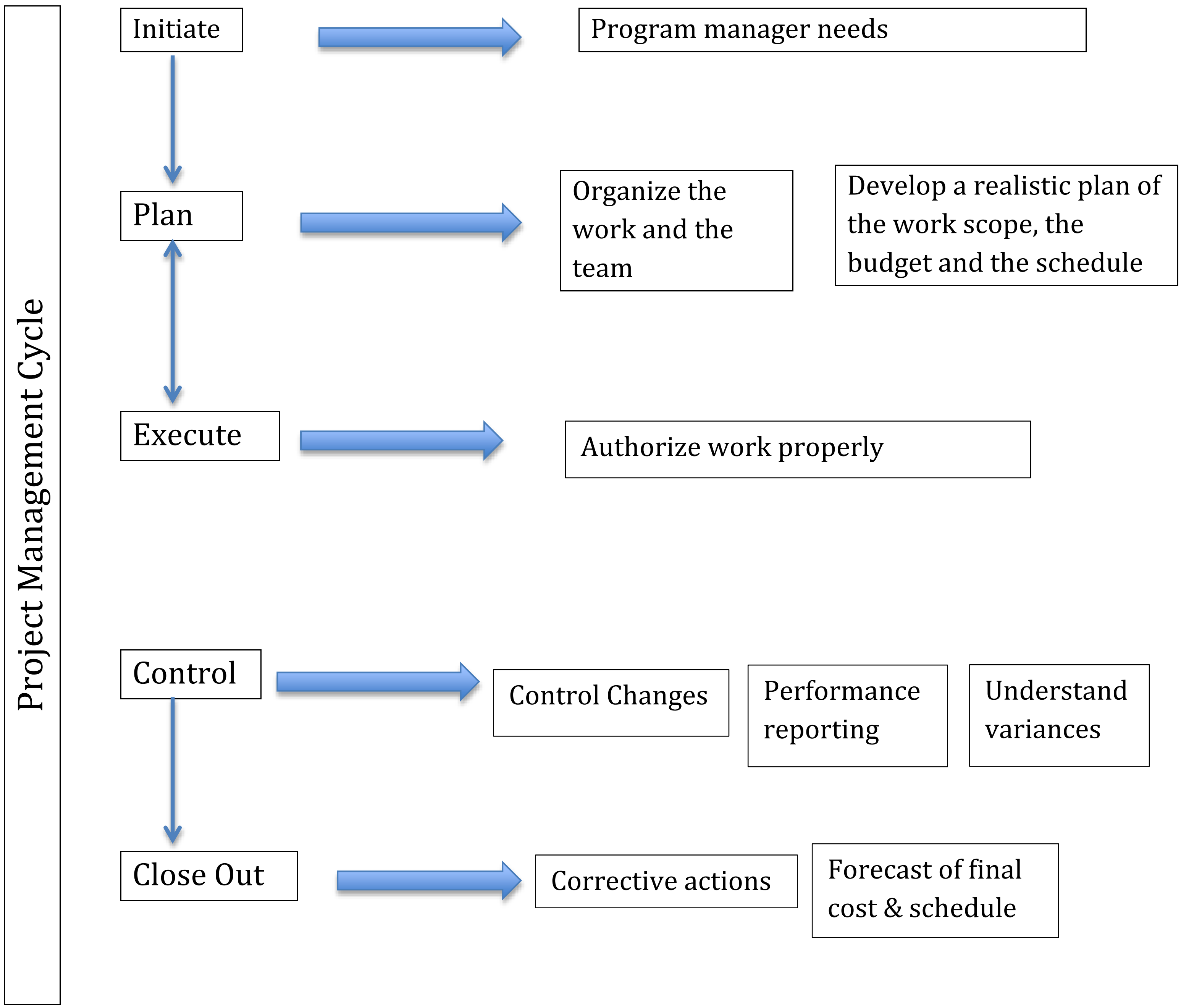


Figure 11 EVA System and Program Management

2.8 Implementation Requirements for EVA

The following are requirements established by Fleming & Koppelman, for the implementation of Earned Value Analysis in all projects (Fleming & Koppelman, 1996):

- **Define work scope**

You must define 100% of the work scope using a Work Breakdown Structure (WBS).

If you do not define 100% the constituents of the project, how can you measure the project performance in definite way?

- **Create an Integrated Bottom up Plan**

By combining the critical process including defined work scope, schedule and estimated resources into an integrated bottom up of detailed measurement cells called "control account plans" [CAPs]

- **Formally Schedule Control Account Plan (CAPs)**

Each of the defined CAPs must be planned and scheduled with a formal scheduling system.

- **Assign each CAP to an organizational unit for performance**

Each of the defined CAPs must be assigned to a permanent functional responsible for performance. This assignment effectively commits the executive to oversee the performance of each CAP.

- **Establish a Baseline that summarize CAPs**

A total project performance measurement baseline must be established which represents the summation of the detailed CAPs. Baseline must include all defined CAPs plus any management (Contingency) reserve that may be held by the project manager.

If the management reserves (MR) are not given to the project manager but are instead controlled by a senior management committee they should be excluded from the Project Performance Baseline.

- **Measurement Performance against Schedule**

Periodically, the projects schedule performance against the planned master project schedule must be measured.

The difference between the work accomplished and work planned constitute the (SV) in terms of Earned Value.

- **Measure cost efficiency against cost incurred**

Periodically, measure the project cost performance efficiency rate which represents the relationship between the project's BCWP performed against Cost incurred (ACWP) to achieve the Earned Value (EV).

- **Forecast final cost based on performance**

Periodically, forecast the project’s final cost requirements (EAC) based on its performance against plan.

- **Managing Remaining Works**

Continuously manage the project’s remaining works.

- **Manage BCWS Changes**

Continuously, maintain the project’s BCWS by managing all changes to the Budgeted Cost of Work Packages (BCWS). Any performance BCWS quickly becomes invalid if it fails to incorporate changes onto the approved BCWS either by the addition to or elimination of added work scope.

2.9 Project Control

Project Control focuses mostly on monitoring and reporting the execution of project plans related to scope, schedule and cost, along with quality and risk (to keep the performance results within acceptable range).

As a performance management methodology, EVA adds some critical practices to the project management process. These practices occur primarily in the areas of project planning and control and are related to the goal of measuring, analyzing, forecasting and reporting cost and schedule performance data for evaluation and action by workers, managers and other stakeholders as shown in the Figure (12).

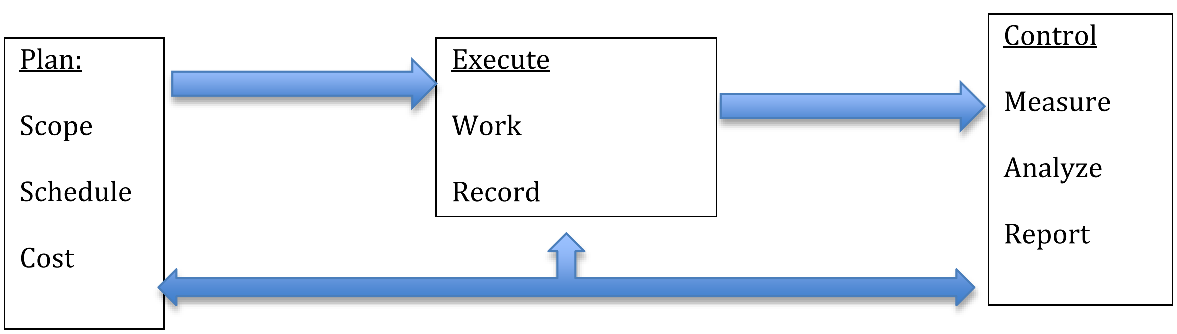


Figure 12 EVA and the Basic PM Process

During the project planning process group, EVA requires that BCWS be established. This requirement amplifies the importance of project planning principles, especially those related to Scope, Schedule and Cost. EVA elevates the need for project work to be executable and manageable, and for the workers and managers to be held responsible and accountable for its performance.

2.9.1 Scaling EVA to fit varying situations

Project situation can and do vary in numerous ways. EVA, as well as project management, needs to be tailored to fit the specific situations if it is to be effective and efficient. Project situations vary along two fundamental dimensions: The significance and the uncertainty of the project. The first has to do with the impact of success or failure and the second has to do with the likelihood of success or failure. Factors that affect the significance include financial, political and environmental considerations, while factors thus contribute to project uncertainty include the size, complexity and duration.

Figure (13) indicates as the project significance and uncertainty increases the rigor with which EVA is applied also needs to increase. As shown in the hypothetical model of the "risk-rigor" relationship.

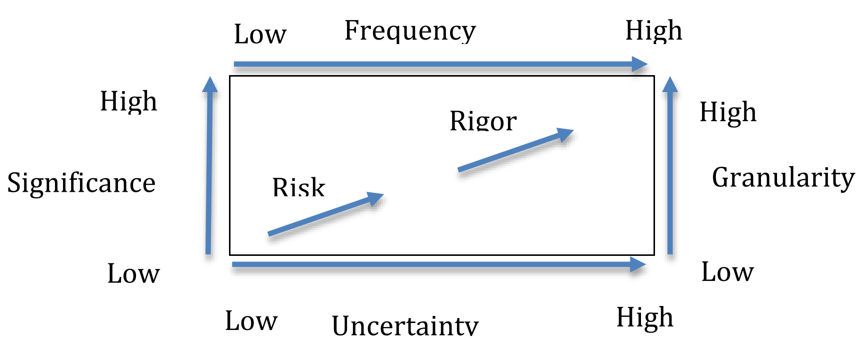


Figure 13 EVA Rigor as a Function of Project Risk

Therefore, there are two basic dimensions related to the application of EVA, the granularity and the frequency of the measurement of project performance.

Granularity, is defined as the level of details to which the project work scope is broken down using a WBS. Frequency, is defined as the time interval at which project performance is obsessed, analyzed and reported, ranging from weakly to monthly or longer. EVA can be scaled along these two dimensions (granularity & frequency) to achieve the degree of rigor requires by the significance and the uncertainty of the project.

2.10 Benefits of Earned Value Analysis (EVA)

The benefits of EVA are outlined in the following: (Christensen 1998) (Fleming & Koppelman 1999) .

1. Provides single management control system to provide accurately/reliable and timely performance data.
2. Provides integrated scope of Work, Schedule and Cost using a Work Breakdown Structure (WBS).
3. Actual performance at the 15% complete point can be used to predict final performance. (Comparative analysis).
4. Cumulative Cost Performance Index (CPIc) measures efficiency of teams using resources and can be used to predict the final range of costs, (as an early warning signal).
5. The Scheduled Performance Index (SPI) is useful in assessing how much work has been accomplished, (measure teams efficiency in measuring the program as well as early warning signal).
6. The cumulative Cost Performance Index (CPIc) provides a statistical basis for a “best case” final estimate.
7. The CPI and SPI indices may be combined to statically forecast the “most likely” final estimate.
8. The Periodic Cost Performance Index for Performance (CPIp) calculated by actual and Earned Value, may be used to monitor weekly or periodic production progress.

9. Management should use "Management by Exception" to focus on significant variances to the plan and apply timely corrective actions (reduce information overload).

   It's a quantitative characteristics.

Figure (14) identifies qualitative characteristics that a report should possess to be useful for decision making.

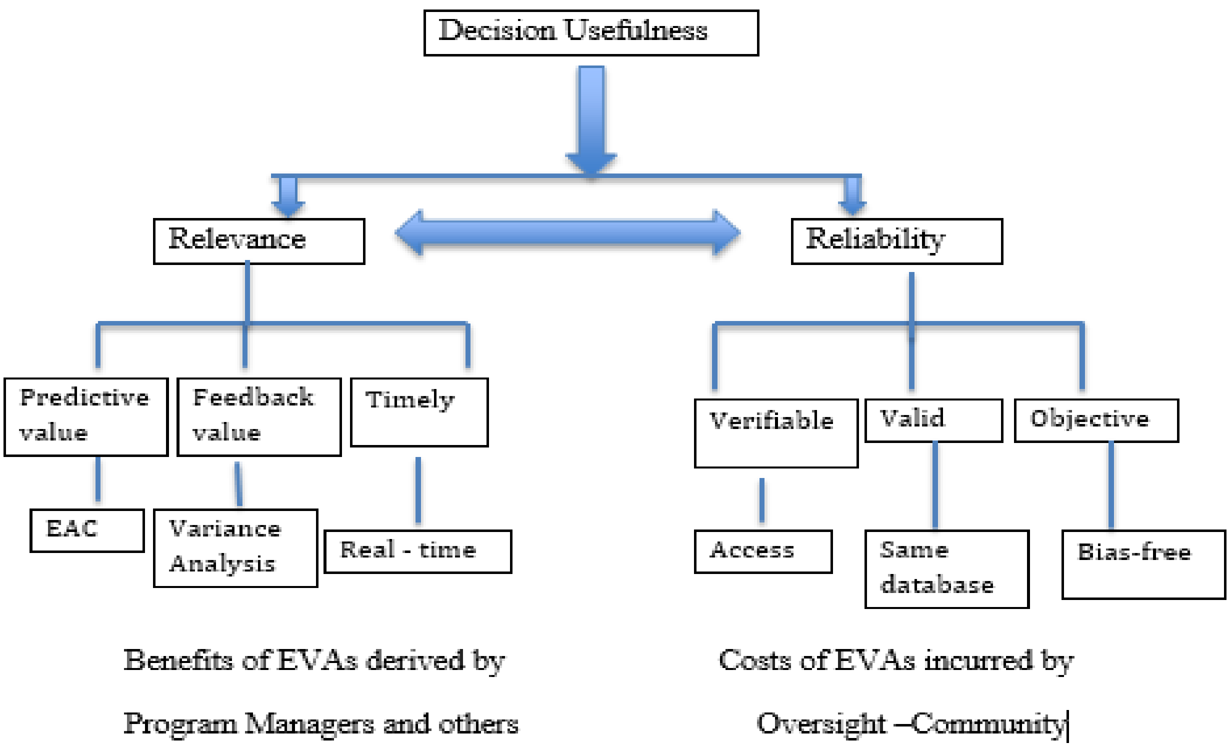


Figure 14 Relevance and Reliability of EVAs Qualitative Characteristics.

2.10.1 Limitations of Earned Value Analysis (EVA)

1. The EVA schedule indicators (SV & SPI) are contrary to expectations of project team and project manager as they are reported in units of cost rather than time. Because cost is the unit of measure, the schedule indicators are counterintuitive and require a period familiarization before EVA users and project stakeholders become familiar with them. (Kym Henderson).
2. Because EVA schedule indicators are expressed in units of cost, comparison with time based network schedule indicators (e.g., the Critical Path Method (CPM) calculated date) is very difficult.
3. The much more serious issue where by the EVA Schedule Indicator (SPI) always returns to "One" at project completion.

   The BCWP always equals the final BCWS, the BAC. Therefore, the SV always returns to "Zero" and SPI always return to "One" irrespective of duration based project delay.

   The schedule indicators also fail for projects which continue to execution beyond the planned completion date. (Henderson 2004).

   * At last 1 / 3 completion, the indicator SPI loses its management value and becomes misleading "gray time area" for the rest of project. (it shows improvement while project reporting late).

4. It gives rough forecast of final time duration indicators (EAC) when calculated beyond 15% completion. (Fleming and Koppelman,1999

Chapter 3. Earned Schedule

Earned Schedule (ES), is a relatively new method for analyzing schedule performance. It is a derived application of Earned Value Analysis (EVA). It was developed 11 years ago, by Walter Lipke in 2003. It focuses significantly on monitoring and forecasting project schedule performance in terms of units of time and not on cost. This facilitates the ability to identify constraints, impediments and the possibility of re-work at the task level which is very useful for management purposes, Earned Schedule can be applied at different levels of project planning and control. Using this concept, the project manager can analyze schedule performance at virtually any level desired – control accounts, work packages and path activities.

The concept behind Earned Schedule (ES), is to "identify the time at which the amount of Earned Value accrued should have been earned" (Lipke, 2003). By determining this time, time based indicators can be formed to provide more reliable schedule variance and performance efficiency management information.

Earned Schedule (ES) is not limited to only the total project duration, but its application can be extended to different intervals of project life-cycle (Lipke, 2011). All that is required is to view the subject of the analysis as if it is the total project.

The creation of ES and the derivative time –based Schedule Performance Efficiency, i.e., SPI_t, facilitate forecasting the duration of the project and its completion date more realistically than EVA does.

3.1 Earned Schedule Concepts and Calculations

While EVA methods produce cost-based performance indicator SV and SPI (Fleming & Koppelman, 2003) they are not reliable/robust metrics in project in which its duration exceeded the BCWS planned end date. They are also unreliable schedule metrics in the later stages of project. (2/3 completion percent). The ratio (PD / SPI) does provide a time based measure, but it is still limited because of its dependence on SPI, a performance measure based on cost and bound by the relationships among BCWP, BCWS and BAC. Which are non-linear equations (as 90% of the commercial construction projects are non-linear). Consequently, we can see EVA method inability / deficiency to provide meaningful / precise schedule for projects that have exceeded their planned duration as SV and SPI start converging to zero and one respectively (show improvement) while the project is still performing late. This irregular behavior of SPI made Project Managers less confident of time schedule. The search for better schedule performance metrics led to the development of the Earned Schedule method based on Earned Value data. The goal of Eared Schedule study is to have a “set of schedule indicators which perform correctly over the entire period of project performance”. (Lipke, 2009) and facilitate the accuracy of forecasting the duration of the project and its completion date i.e., SPI_t

Figures (15) and (16) respectively illustrate the behaviors of the EVA Cost and Schedule Indicators over time. In the example, project completion was scheduled for January of the second year but completed until April .The Cost Indicators behave differently from those for Schedule. The cost indicators appear to establish a trend with some variation. Similarly, the schedule indicators initially appear to establish a trend, but eventually begin moving towards their end result, “Zero Variance” (Fig 15) and an Index value equal ‘One‘ (Fig 16). This irregular behavior of SV and SPI occurs without fail for every project finishing late, no matter how late. This abnormal behavior of the schedule indicators with its misinterpretations and misunderstandings weakens the initiative to broaden the acceptance and application of EVA.

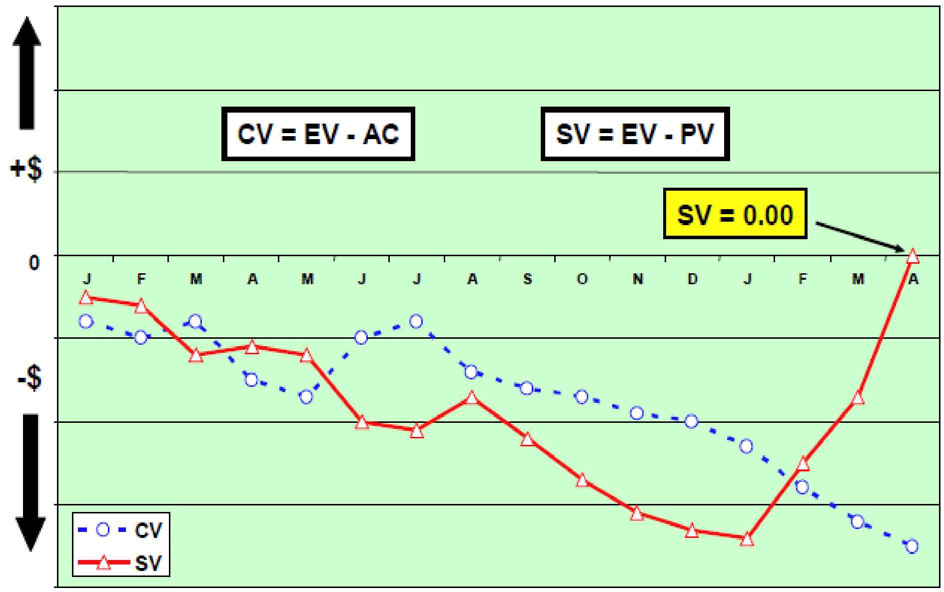


Figure 15 Cost and Schedule Variances

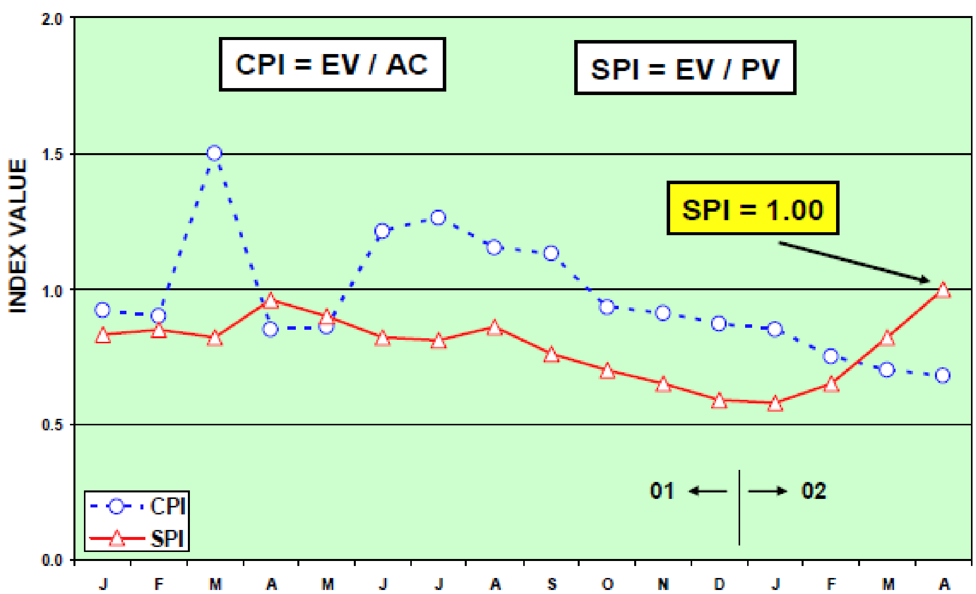


Figure 16 Cost and Schedule Performance indices example

One may question, what is causing this irregular behavior? Referring back to Fig (1), the Cost Indicators are referenced to ACWP, whereas the Schedule Indicators are referenced to the BCWS curve. It is this reference to BCWS that causes the problem for the Schedule Indicator, (Lipke 2012). The end – point of the BCWS curve as mentioned earlier, is the BAC for the project. The end – point for the BCWP is, likewise, BAC. Thus, as the BCWP approaches project completion in early finish or on time, it converges to the BAC. However, in the case of a Late Finish Project, BCWS equals BAC prior to project completion, while BCWP incrementally achieves the Value in later time, (beyond the planned Value or BAC). From this explanation, one can understand the behavior of schedule indicators shown in Figures (15) and (16) above. Schedule Variance ($SV_\$$) must converge to Zero at project completion. While Schedule Performance Index ($SPI_\$$) Concludes at One.

The irregular behavior of the Schedule Indicators see Fig (17a , 17 b) causes additional problems for project managers. At some point in time (70% --80% completion), it becomes obvious when the $SV_\$$ and $SPI_\$$ Indicators have lost their management value. But, there is a preceding "grey time area" where the manager cannot be certain of the reliability of the indicator and be confident in reacting to it. This uncertainty has caused the application of EVA to be focused on Cost Performance Control, whereas the Schedule Analysis features are all but ignored. The formation of "grey time area" in every project finishing late clearly can be observed. Let, BAC = 9M, for 13 weeks Planned Duration (PD) project. The project is running late from the beginning with a values of $SPI_\$$ of 0.5, 1.125,0.69 (calculated by BCWP / BCWS values) and so on till recording 0.67 at 13th week, which is the planned duration (PD). However, when it started executing late, an improvement of the performance indicator is clearly noticed which is against the reality, and continue to improve till it reaches a value of One at the end of 20th week.

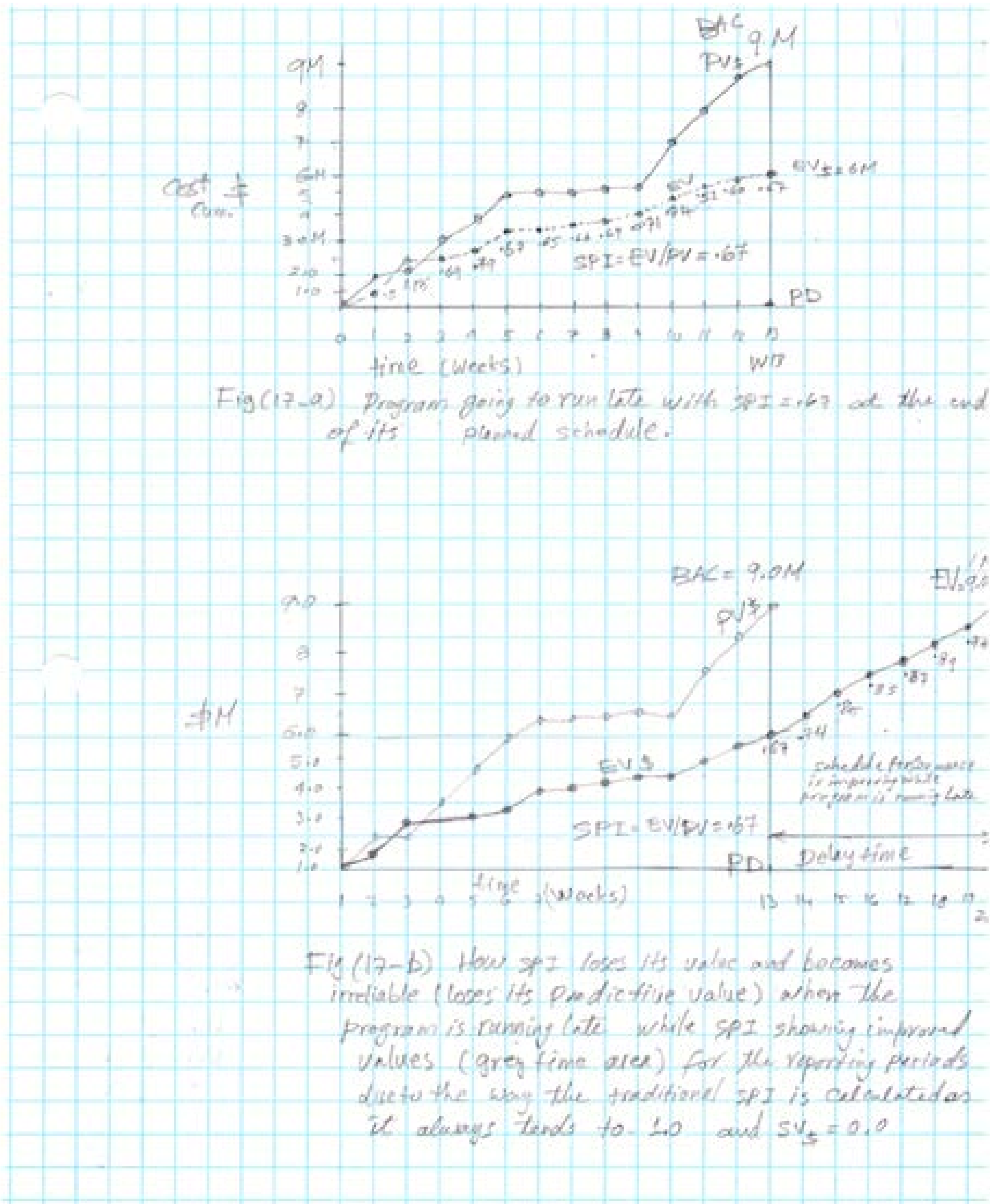


Figure 17 SPI behavior while project is running late

3.2 Earned Schedule Measures and Indicators

The concept of Earned Schedule (ES) is analogous to the concept of Earned Value. However, instead of using cost for measuring Schedule Performance, the unit is “Time.” The fundamental concept of ES is to determine the time at which the BCWP accrued should have occurred; i.e., the time associated with point on the BCWS curve where PCWS equals BCWP. The significance of the Earned Schedule Concept is that the associated schedule indicators behave reliably throughout the entire period of project performance. Figure (18) below shows the mathematical model of interpolation, and Figure (19) shows mathematical representation Earned Schedule into Earned Value Analysis graphs.

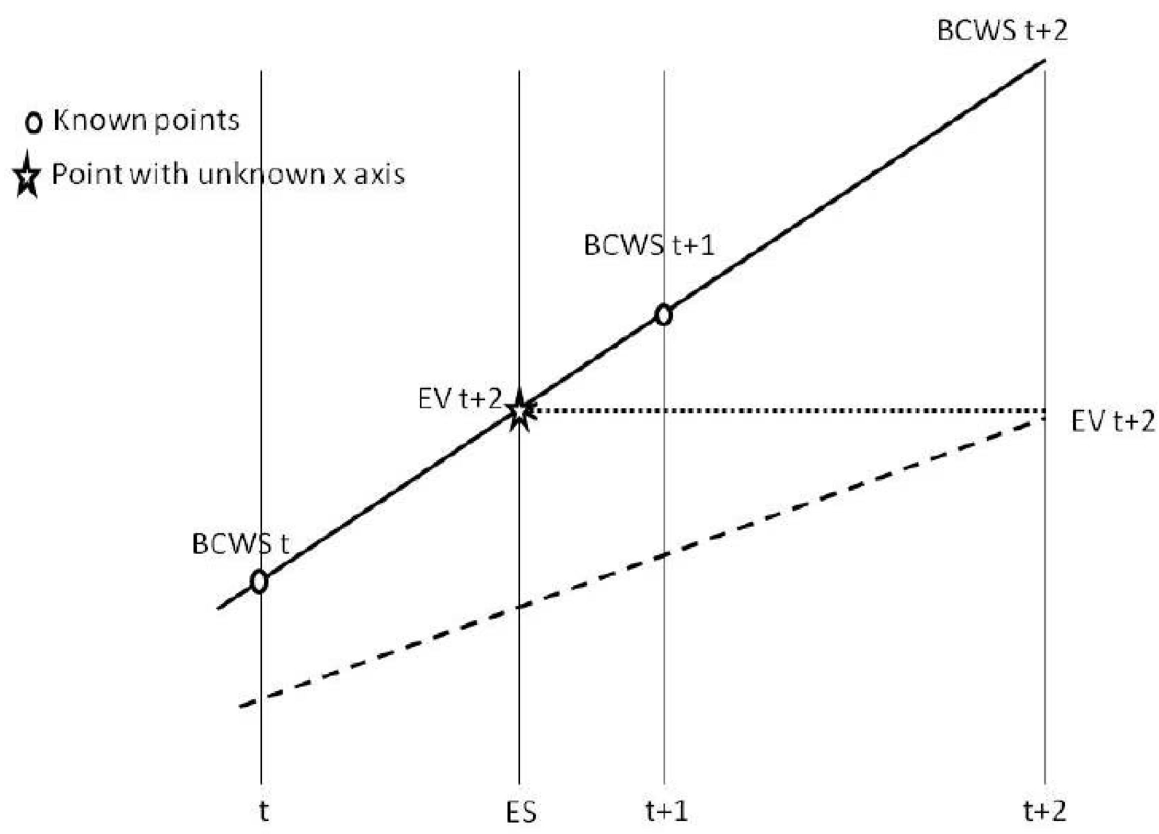


Figure 18 Mathematical Model of Interpolation

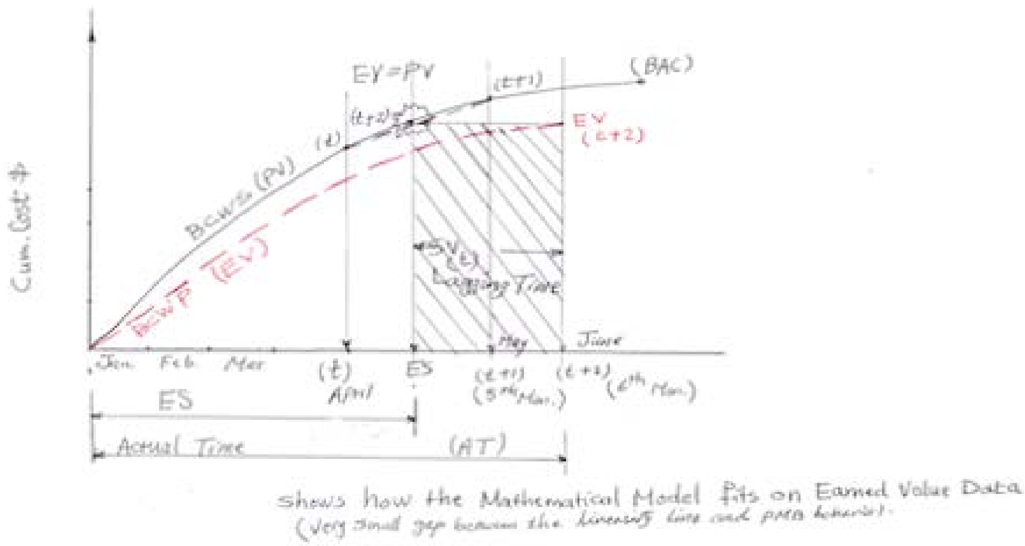


Figure 19 Mathematical representation (Model) of Earned Schedule

To determine the Earned Schedule one uses the following equation

$$ES = C + I$$

Equation 11

Where:

C stands for the number of time period increment of BCWS curve in which BCWP equal or greater than BCWS. “C” is always an integer number.

“I” is a fraction amount equal to the portion of BCWP extending into the incomplete time divided by the total BCWS planned for the same period.

So, the general configuration of equation 11 is shown below

$$ES = C + [(BCWP(t+2) - BCWS (t)) / (BCWS (t+1) – BCWS (t))]\ldots\ldots$$

Equation 12

ES is computed as an interpolation process a shown in graphic representation in Fig (20).

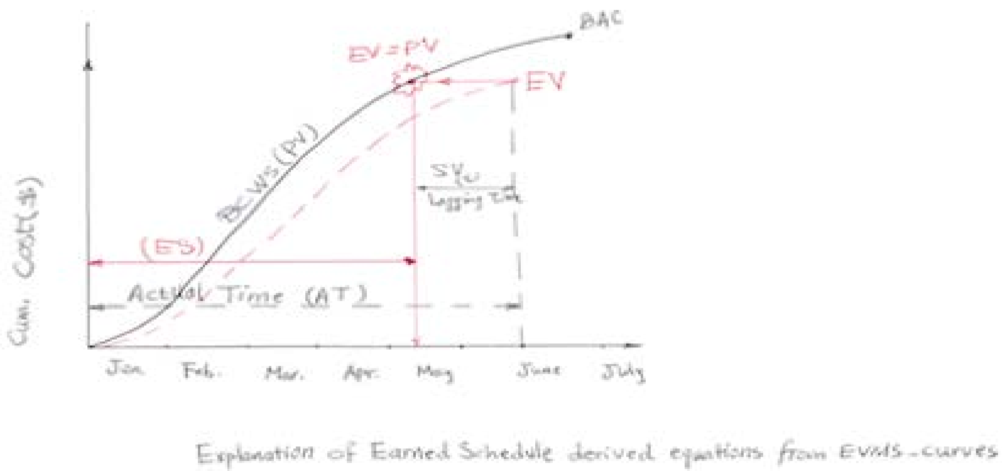


Figure 20 Earned Schedule derived equations from EVA & S – Curves.

The value of time incremental (C) is easily determined by counting the number of time increments of the PMB that satisfy the condition, BCWP ≥ BCWS. The value of (I) is calculated by employing the linear interpolation method for the (C+ 1) period of the BCWS curve. The amount of BCWP extending into the (C+1) period is equal to the difference of (BCWP) minus (BCWS), where (BCWS) is determined from the BCWS value associated with period (C). The periodic amount of BCWS for period (C+1) is the difference $BCWS_{c+1}$ minus BCWS. The fraction (I) is calculated from the quotient of these two values as follow:

$$I = (BCWP_{t+2} – BCWS_t) / (BCWS_{c+1} - BCWS_t)$$

Equation 13

When determined, the two values (C and I) are added to become the value of ES.

So, $ES = C + I$

Where the units are in time periods, commonly months or weeks.

Using the ES measure, indicators are established which behave appropriately and analogously to the cost indicators (CV and SPI):

$$\text{Schedule Variance} \quad SV_t = ES - AT$$

Equation 14

$$\text{Schedule Performance Index } SPI_t = ES \,/\, AT$$

Equation 15

Where AT is the actual time, (referring to Fig 20) .

The Schedule Variance, SV_t, is positive when the ES exceeds AT, and of course, is negative when it lags. The Schedule Performance Index, SPI_t, is greater than 1.0 when ES exceeds AT, and is less than 1.0 when ES is less than AT. These proposed indicators are completely analogous to the EVA Cost Indicators, CV and CPI. The proposed Schedule Indicators are referenced to AT, similarly to the EVA Cost Indicators referenced to ACWP.

Referring back to Fig (20), the performance portrayed is of a project having schedule performance lagging its plan. It can be observed that the vertical dashed line from the point on the BCWS curve where BCWS = BCWP intersects the time axis at a point occurring sometime in the month of “May “. The inset of the figure shows the calculation of ES and the value for AT. The time period at which the BCWP accrued is reported, is the end of June, AT = 6. The whole number component of ES, i.e, C, is associated with BCWS at the end of April or month (4) the interpolated portion of ES, I, is spelled out in the inset of the Figure as:

$$I = [\text{EV projected} - \text{PV April}] / [\text{PV May} - \text{PV April}]$$

Where BCWP is larger than the BCES value for April, but smaller than the BCWS value for May. Thus, the interpolation is made for May. Table 6 summarizes all these expressions

Method	SPI	$IEAC_t$
EVM	BCWP (EV) /BCWS (PV)	1. AT+[(BAC – EV) / BCWS avg. $_{WR}$] 2. PD / SPI 3. AT + [(BAC – EV) / EV avg. $_{WR}$]
ES	ES / AT Where ES = C + I	1. PD / SPI_t 2. AT + ETC ETC t =(TD – ES) / SPI_t

Table 6 Summary of EVA and ES Performance Metrics

- AT: Actual time where PV and E V are reported
- WR: work rate that converts work into time.
- BCWS avg.: value is used when the program is expected to progress according to plan

  BCWS avg. = BCWS cum / n
- BCWP avg. is used to depict performance that is expected to follow the current SPI trend, BCWP / n.
- n: is the total number of time increments within AT.
- C: is the total number of time increment in which BCWP has been accomplished.
- I: partial time in which partial BCWP has been occurred within AT.

Now, let us check the viability of ES equation by assigning some hypothetical numerical values and working out the calculations as shown in the following example.

Example 1

Assume we are reporting on the end of June in Fig (20). So, AT = June (6), with a

Corresponding BCWP of ($1000) assumed at reporting date. Which is the same value after being projected horizontally on BCWS curve i.e., = $ 1000. So,

$$BCWS \text{ on }_{April} = \$ 900;$$

$$BCWS_{May} = \$ 1100 \text{ and}$$

PD = 7.0 Month. (Planned end).

Solving for I = [1000 -- 900] / [1100 -- 900] = 0.50 Month. EV has taken to accrue. So,

$$ES = 4 + 0.5 = 4.5 \text{ Month (total time)}$$

$$SPI_t = ES / AT ; \quad 4.5 / 6 = 0.75$$

$$ETC_t = (7 – 4.5) / 0.75 = 3.333 \text{ Month for work remaining, and}$$

$$EAC_t = 4 + 3.33 = \mathbf{7.33 \ Month}$$

Now, using the same example but this time using EVA parameters,

We have BCWP = $ 1000 (As of reporting date), and BCWS = $ 1100 (as already assumed). So,

$$SV = BCWP – BCWS$$

Using terms of volume of work or cost $1 =1 unit volume of work one gets:

$$SV = 1000 - 1100 = -100$$

SV % = SV / PV as of date will be

$$SV\% = 100 / 1100 * 100 = -9\% \quad \text{decrease}$$

Reporting date is June, which is 6^{th} month. So,

$$0.09 * 6 = 0.54 \text{ mon. late;}$$

$$SV\% = (0.54 - 0.5) / 0.54 * 100 = 7.407\% \quad \text{more time}$$

$$SPI = BCWP / BCWS, \; 1000 / 1100 = 0.909$$

So, EAC = PD / SPI = 7 / 0.909 **= 7.70 Month**

The difference is (7.70 – 7.33) / 7.33 * 100 = 5 % more than ES est. time.

To demonstrate the concept of Earned Schedule further, let us consider the following example

Example 2

Considering the hypothetical data created for BCWS and BCWP. The data, along with the calculated results for ES, i.e., SV_t and SPI_t are tabulated in table (7) below for early finish project, and table (8) for late finish project respectively.

EVA method (January)

BCWS for month (Jan) = \$ 106

BCWP for month (Jan) = \$ 116

$$SV_{\$} = BCWP - BCWS \text{ or } \quad SV_{\$} = 116 - 106 = \$\,10$$

A positive sign indicate progress ahead of planned.

$$SPI_{\$} = BCWP / BCWS, \quad \text{or} \quad SPI_{\$} = 116 / 106 = 1.095$$

A ratio over 1 indicates the project ahead of plan, good efficiency of time, the project team is achieving. So,

$$IEAC = PD / SPI_{\$}, \quad \text{or} \quad IEAC = 12 / 1.095 = 10 .968$$

This imply a month less than planned.

ES method (January)

$$I = (BCWP_{Jan} – BCWS) / (BCWS_{Jan} – BCWS) ,$$

$$I= (116 – 0) / (106 – 0) = 1.094$$

$$ES = C + I,$$

$$ES = 0 + 1.094 = 1.094 \quad \text{Month.}$$

$$SV_t = ES – AT$$

$$SV_t = 1.094 – 1 = 0.94 \quad \text{Month. (project ahead of plan).}$$

$$SPI_t = ES / AT, \quad 1.094 / 1 = 1.094$$

So,* $IEAC_t = PD / SPI_t$, $IEAC_t = 12 / 1.094 = 10.968$ mon. less than planned.

The forecasts obtained by either method are the same since the percent completion is less than 15%, and project is progress ahead of planned.

The star (*) above indicates the indicator IEAC t = PD /SPI t, has been used as the project is progressing as planned. For more details, refer to table (6).

EVA method (February)

We have the data, BCWP = $ 222, BCWS = $ 201,

$$SV_{\$} = BCWP – BCWS, \quad 222 – 201 = \$ 21$$

$$SPI_{\$} = BCWP / BCWS \quad 222 / 201 = 1.104$$

$$IEAC = PD / SPI_{\$} = 12 / 1.104 = 10.875 \text{ mon. less than planned.}$$

ES method (February)

$$I = (BCWP_{Feb.} – BCWS_{Jan}) / (BCWS_{Feb} – BCWS_{Jan})$$

$$I = (222 - 106) / (201 – 106) = 1.221$$

$$ES = C + I, \quad 1.0 + 1.22 = 2.221 \text{ Month.}$$

$$SPI_{t} = ES / AT \quad 2.221 / 2 = 1.110$$

$$IEAC_{t} = PD / SPI_{t} \quad 12 / 1.110 = 10.810 \text{ Month is also less than planned.}$$

Calculating month by month by both methods lead to similar conclusions until the month of October. Let us see what happens, for the month of November

EVA method (November)

We have the data BCWS = $ 2760, and BCWP =$ 2854

$$SV_{\$} = EV – PV \text{ or } SV_{\$} = 2854 – 2760 = \$ 94$$

$$SPI_{\$} = 2854 / 2760 = 1.034$$

$$IEAC = PD / SPI_{\$} \text{ or } IEAC = 12 /1.034 = 11.60 \text{ Month less than planned.}$$

ES method (November)

$$I = (BCWP_{Nov.} - BCWS_{Oct.}) / (BCWS_{NOV} - BCWS_{Oct.}),$$

$$I = (2854 - 2666) / (2760 - 2666) = 2$$

$$ES = 10 + 2 = 12 \text{ month}$$

This means that Earned Schedule of 12 months' work has been occurred in 11 months only.

$$SV_t = ES - AT, \text{ or } SV_t = 12 - 11 = 1.0 \text{ Month less than planned.}$$

$$SPI_t = ES / AT, \quad 12 / 11 = 1.091$$

$$IEAC_t = PD / SPI_t, \text{ or } IEAC_t = 12 / 1.091 = 11.0 \text{ Month, the job has been done!}$$

The difference between two methods is for ES and EVA is

$$SV\% = (11.6 - 11) / 11 * 100 = 5.45\% \quad \text{less than EVA forecast.}$$

Therefore, ES yields a more realistic and accurate time forecast than EVA

The resulting SV_t and SPI_t for each month are tabulated in table (7) and plotted in Figure (21) below for early finish project. The resulting $SV_\$$ and $SPI_\$$ for each month plotted in Figure (22) below for early finish project

	Jan	Feb	Mar	Apr.	May	Jun	July	Aug.	Sep.	Oct.	Nov.	Dec.
						Early Finish						
BSWSt	106	201	516	846	1176	1476	1806	2136	2436	2666	2760	2854
BCWP $	116	222	532	871	1216	1526	1861	2191	2501	2744	2854	-
SV $	10	21	16	26	40	50	55	55	65	75	63	-
SPI $	1.095	1.100	1.031	1.030	1.034	1.034	1.03	1.026	1.027	1.028	1.023	-
Month Count	1	2	3	4	5	6	7	8	9	10	11	12
ES (Month)	1.094	2.24	3.050	4.076	5.121	6.167	7.167	8.166	9.217	10.326	12	-
SVt	0.94	0.221	1.050	0.076	0.121	0.167	0.167	0.166	0.217	0.326	1	-
SPIt	1.094	1.110	1.070	1.099	1.024	1.027	1.024	1.020	1.024	1.037	1.091	-

Table 7 Early Finish Project Example 2

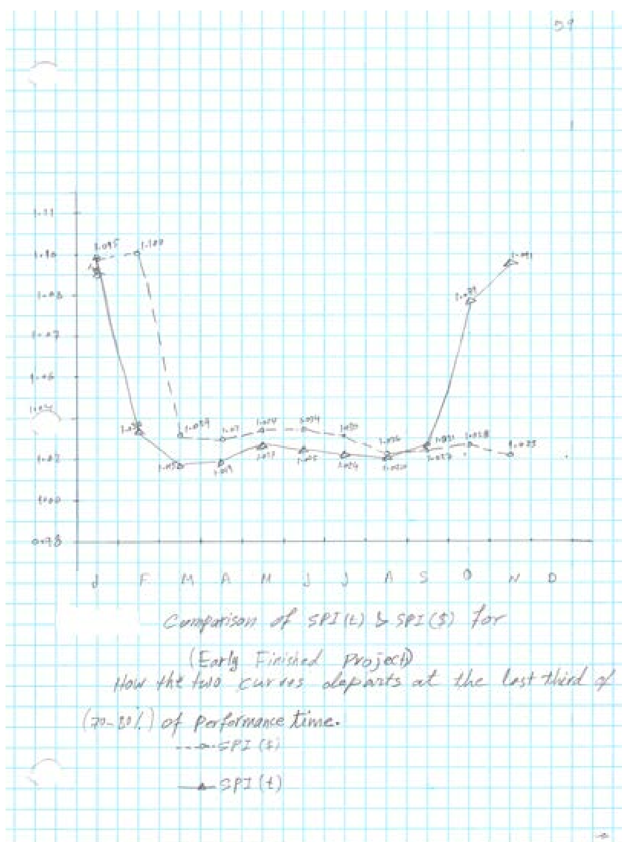


Figure 21 Comparison of SPI $_{(t)}$ & SPI $_{(\$)}$ trend for Example 2

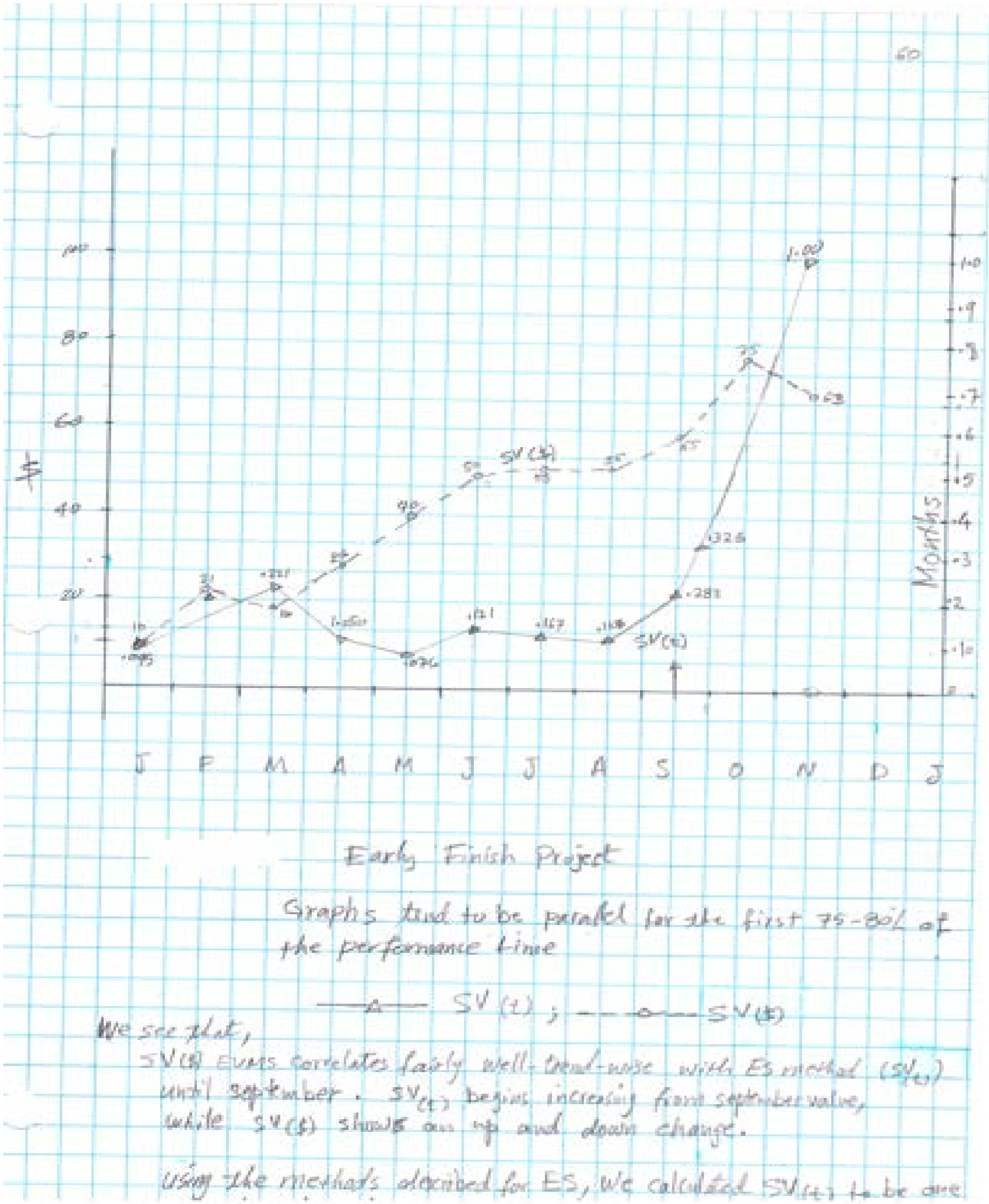


Figure 22 Comparison of SV $_{(t)}$ & SV $_{(\$)}$ Early Finish Project for Example 2

Example 3

Let’s consider an example in which the project is completed late.The summary of all month by month calculations using Earned Value, and Earned Schedule are shown in Table (8)

EVA method (January)

Considering (January) as beginning of the project, the data are,

$BCWP_{cum}$ = $100, and $BCWS_{cum}$ =$110,

$SV_{\$}$ = 100 – 110 = - $ 10 (minus sign indicates late progress).

$SPI_{\$}$ = BCWP / BCWS 100 / 110 = 0.9090

IEAC = PD / $SPI_{\$}$ 12 / 0.9090 = 13.20 Month.

EVA method (January)

I = ($BCWP_{Jan}$ – 0) / ($BCWS_{Jan}$ - 0) , (100 - 0) / (110 – 0) = 0.9090

ES = C+ I, 0+ 0.9090 = 0.9090 Month.

SV_t = ES – AT, 0.9090 – 1 = - 0.09 Month late

SPI_t = ES / AT, 0.9090 / 1 = 0.9090

So, IEAC = PD / SPI t, 12 / 0.9090 = 13.20 month.

Same values are expected to be identical for 15% completion only.

EVA method (February)

BCWP = $ 185, and BCWS = $ 205

$SV_{\$}$ = BCWP – BCWS, 185 – 205 = - $ 20

$SPI_{\$}$ = BCWP / BCWS, 185 / 205 = 0.900

IEAC = PD / $SPI_{\$,}$ 12 / 0.900 = 13.34 Month.

EVA method (February)

I = ($BCWP_{Feb}$ – $BCWS_{Jan)}$ / ($BCWS_{Feb}$ – $BCWS_{Jan}$),

I = (185 – 110) / (205 – 110) = 0.789

ES = C + I, 1+ 0.789 = 1.789 Month.

SV_t = ES – AT, 1.789 – 2 = - 0.210 month delay in EV to occur as planned.

SPI_t = ES / AT, 1.789 / 2 = 0.894

So, $IEAC_t$ = PD / SPI t, 12 / 0.894 = 13.420 Month. More than EVA method

Calculating month by month by both methods lead to similar conclusions until the month of November. Let us see what happens, for the month of December

In Dec. the last month of scheduled duration, the calculations of time duration are as follow:

EVA method (December)

EV = \$ 2690 and PV = BAC = \$ 2854

$SV_{\$}$ = BCWP – BCWS, 2690 – 2854 = - \$ 164

$SPI_{\$}$ = BCWP / BCWS, 2690 / 2854 = 0.942

And IEAC = PD / $SPI_{\$}$ 12 / 0.942 = 12. 731 Month.

ES method (December)

$BCWP_{Dec}$ = \$2690, and $BCWS_{Nov}$ = \$2765

I = (2690 – 2765) / (2854 – 2765) = - 0.442

ES = 11 – 0.442 = 10.60 Month.

SV_t = ES – AT, 10.6 – 12 = - 1.84 Month.

SPI t = ES / AT, 10.60 / 12 = 0.846

So, $IEAC_t$ = PD / SPI_t, 12 / 0.846 = 13.60 Month which is more realistic than EVA forecast.

Now, solving for the delayed time the project undergoing, which starts on January of next year, say (2002), we have the following data,

EVA method (January 2002)

$BCWP_{cum}$ = \$2695, and $BCWS_{cum}$ = BAC = \$2854,

$SV_{\$}$ = BCWP – BCWS, 2695 – 2854 = - \$159

$SPI_{\$}$ = BCWP / BCWS, 2695/2854 = 0.944

IEAC = PD / $SPI_{\$}$ 12 / 0.944 = 12.701 Month.

ES method (January 2002)

Here, we have no planned value yet to be used in the Baseline, as PV has already reached the BAC much earlier than BCWP reaches BCWS at the end of project.

So, using the Percent Complete ratio = Work done / Total work

BCWP = % complete * BAC,

So, ES = BCWP / BAC * PD , 2695 / 2854 * 12 = 11.45 Month.

SV_t = ES – AT, 11.45 – 13 = - 1.5 Month, late from planned.

SPI_t = ES / AT, 11.45 / 13 = 0.880

So, $IEAC_t$ = PD / SPI_t, 12 / 0.880 = 13.636 Month.

EVA method (February 2002 delayed time)

The data are, EV =$ 2770, and PV = BAC =$ 2854,

$SV_\$$ = BCWP – BCWS, 2770 – 2854 = - $ 84

$SPI_\$$ = BCWP / BCWS, 2770 / 2854 = 0.970

IEAC = PD / $SPI_\$$ 12 /0.970 = 12.37 Month.

ES method (February 2002 delayed time)

ES = 2770 /2854 *12 = 11.64 Month.

SV_t = 11.64 – 14 = - 2.35 Month. late

SPI_t = ES / AT, 11.64 / 14 = 0.831

And $IEAC_t$ = PD / SPI_t, 12 / 0.831 = 14.44 Month.

Considering the March the last month

EVA method (March 2002 delayed time)

The data are as follow;

$BCWP_{cum}$ = $ 2854, $BCWS_{cum}$ =BAC = $ 2854

$SV_\$$ = $ 0,

$SPI_\$$ = 1

IEAC = 12 /1 = 12 Month. meaningless ?

ES method (March 2002 delayed time)

ES = 2854 / 2854 *12 = 12 Month.

$SV_t = ES - AT$,   12 - 15 = - 3 Month late,

$SPI_t = ES / AT$,   12 / 15 = 0.8

And $IEAC_t = PD / SPI_t$, 12 / 0.8 = 15 Month which is realistic and accurate.

The resulting SVt and SPIt for each month are tabulated in table (8) and plotted in Figure (23) below for the late finish project.

Late Finish Project

PC		6.50%	16.64%	27.15%	37.50%	46.25%	56.59%	66.75%	75.50%	80%	92%	94.25%	94.45%	97%	100%
	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct.	Nov	Dec	Jan	Feb	Mar
BCWS	110	205	520	850	1180	1480	1810	2140	2440	2670	2765	2854	0	0	0
BCWP	100	185	475	775	1070	1320	1615	1905	2155	2280	2625	2690	2695	2770	2854
SV	-10	-20	-45	-75	-110	-160	-195	-235	-285	-390	-335	-294	-159	-84	0
SPI	0.905	0.9	0.913	0.911	0.906	0.892	0.892	0.89	0.883	0.854	0.879	0.905	0.944	0.97	1
IEACt	13.23	13.34	13.143	13.172	13.245	13.453	13.453	13.5	13.6	14.051	13.651	13.23	12.711	12.37	12
Month count	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
ES (Month)	0.909	1.789	2.857	3.772	4.670	5.470	6.409	7.288	8.050	8.304	9.526	10.160	11.450	11.640	12
SVt (Month)	-0.090	-0.210	-0.143	-0.228	-0.333	-0.533	-0.591	-0.712	-0.950	-0.196	-1.500	-1.400	-1.500	-2.350	-3
SPIt	0.909	0.894	0.952	0.943	0.933	0.911	0.916	0.911	0.894	0.830	0.866	0.883	0.880	0.831	0.800
IEACt= PD/SPIt	13.200	13.420	12.60	12.725	12.86	13.172	13.100	13.17	13.42	14.46	13.656	13.6	13.63	14.44	15

* From calculations above we can see that EVM Schedule Performance Indicator SPI fails to provide accurate forcast of final duration due to being converged to 1.0 at the end of project while ES Performance Indicators have succeded to provide an accurate and realistic forcasted duration.

Table 8 Late Finish Project Example 3

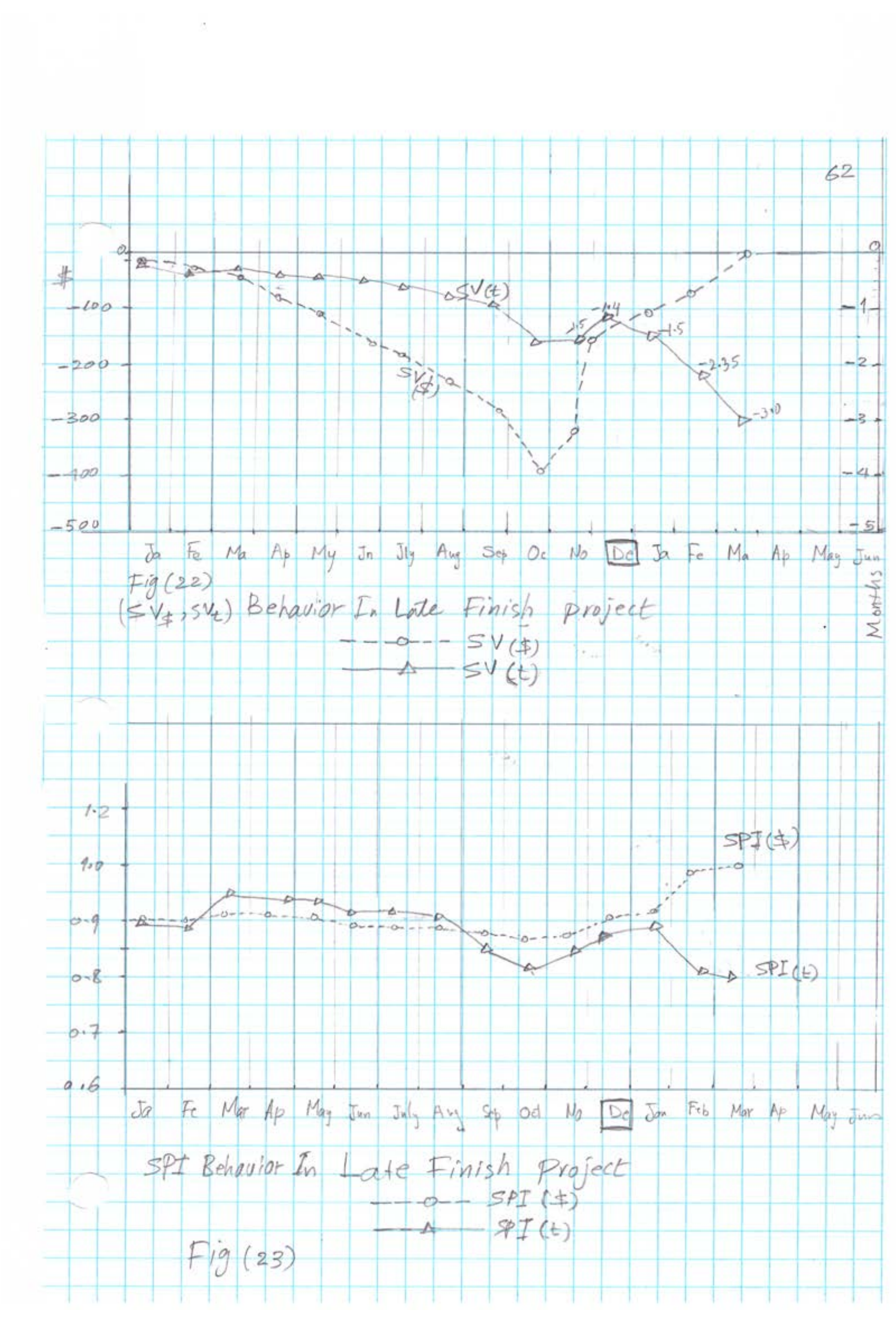


Figure 23 Late Finish Project, Schedule Performance Comparison of example 3

Chapter 4 CASE STUDY

4.1 Earned Value Analysis, Earned Schedule and Building Information Modeling (BIM)

Worcester Polytechnic Institute (WPI) is one of the US earliest technical universities. It was founded in 1865 to create and convoy the latest science and engineering knowledge in ways that are most beneficial to society. WPI's founding motto for Lehr und Kuntz (Theory and Practice) underlines its academic programs. for several years now, faculty and students in the Civil and Environmental Engineering Department and in particular those involved in the construction project management program, have been working together with college administration through WPI'S project-oriented educational system to identify efficient uses and implementation of Information Technology as a two-way avenue that enhances the institution's management information system for new and existing facilities .This activity is now focusing on the use of Building Information Modeling (BIM) as enabler for information integration and more collaborative design, construction and operational process which has been in the industry system since the early 1980s.The following is an overview concise narrative of BIM and project management software process utilized in this mission.

The 3D model is useful for visualizing the shape instead of imagining it, quantifying the construction materials, performing clash detection, creation of cost and time –phased 4D and 5D models in addition to calculating total cost of whole project components with 90% accuracy to be incorporated with EVA and ES "S- curve". Microsoft Project Planner 2013 software is useful for scheduling the work packages (including their assigned Budgeted Costs of work packages along with Actual Spending amounts(ACWP) obtained from the project records) after tabulating them with the same logical task precedencies and interrelationships to be similar to what were used by the prime contractor in order to generate the Gantt chart, critical path, network diagram, ending with S-curve diagram displaying cost time relationships of the scheduled activities so that the EVA and its extension ES data (cumulative cost - time values) would be captured from the S-curve. After this stage, it is possible/suitable to connect the work with BIM tools, such as Navisworks software, and by phasing and integrating the structural components of 3D model to their assigned construction time periods and costs 4D and 5D models are created to reflect the physical progression of time- cost milestones to be incorporated on S-curve. The 4D modeling helps the sub-contractors to detect visually any error or discrepancy on the drawings prior to any phase extension, and to monitor the schedule adherence during the construction phase, while 5D reflects the dynamic relation among the three variables cost- time and scope and shows how a change of one variable affect the other two variables in digital representations.

4.2 Parking Garage Facility

In order to check the applicability/reliability of EVA and ES Schedule Performance Indicators and time forecast duration metrics along with BIM 3D, 4D and 5D simulations on a real project, a Parking Garage with Rooftop Athletic Fields with Synthetics Turf for Soccer at WPI campus was chosen for this study as being of late completion projects.

Description of Facility

In late October 2011, WPI made a decision to build a $20M dollars, 536 cars one-way Parking Garage Project with a rooftop Athletic Field with Synthetics Turf for Soccer, field Hokey, Lacrosse, Rugby and Softball uses at WPI campus. The project includes a small section for restrooms locker rooms, field storage and concession stands. The project was delivered under a contractor-led Design Build System (DB – GMP contract). By Gilbane Building Company

(GBC) with guaranteed maximum price contract $ 20.0 M. to cover the cost of all materials, design, labor, equipment, supervision, insurance and all other aspects considered necessary to construct the facility within nine months only. Construction was started as scheduled on late May, 2012. The Parking and was completed and delivered /occupied in late January 2013, whereas the playing fields were substantially completed in early summer (May, 28, 2013) because the owner's approval to defer the installment of Synthetic Turf after the severe winter months when better weather condition (Temperature and Humidity) allow for Synthetic Turf to be installed as recommended by manufacture.

4.3 Work procedures for Earned value Analysis and Earned Schedule

This section shows how data was collected and processed.

4.3.1 Data collection and Scheduling with Microsoft Project 2013

The extraction of input data and scheduling took considerable time as the records of (budgeted costs and actual spending costs) where recorded three years ago and were not easily referenced in the format for direct EVS and ES calculations. Therefore the original information as collected needed to be processed carefully and judicially to allow for its valid use for this study. Then the first step is composing the main activities (work packages) in such a way to be of analogous order to that used by the prime contractor records, and referring their pertinent sub-activities to each of them as well (See Table 9). The way to configure the Work Breakdown Structure (WBS) is shown in Figure (24) which represents a reference of planning and scope of work making it clear and tangible..

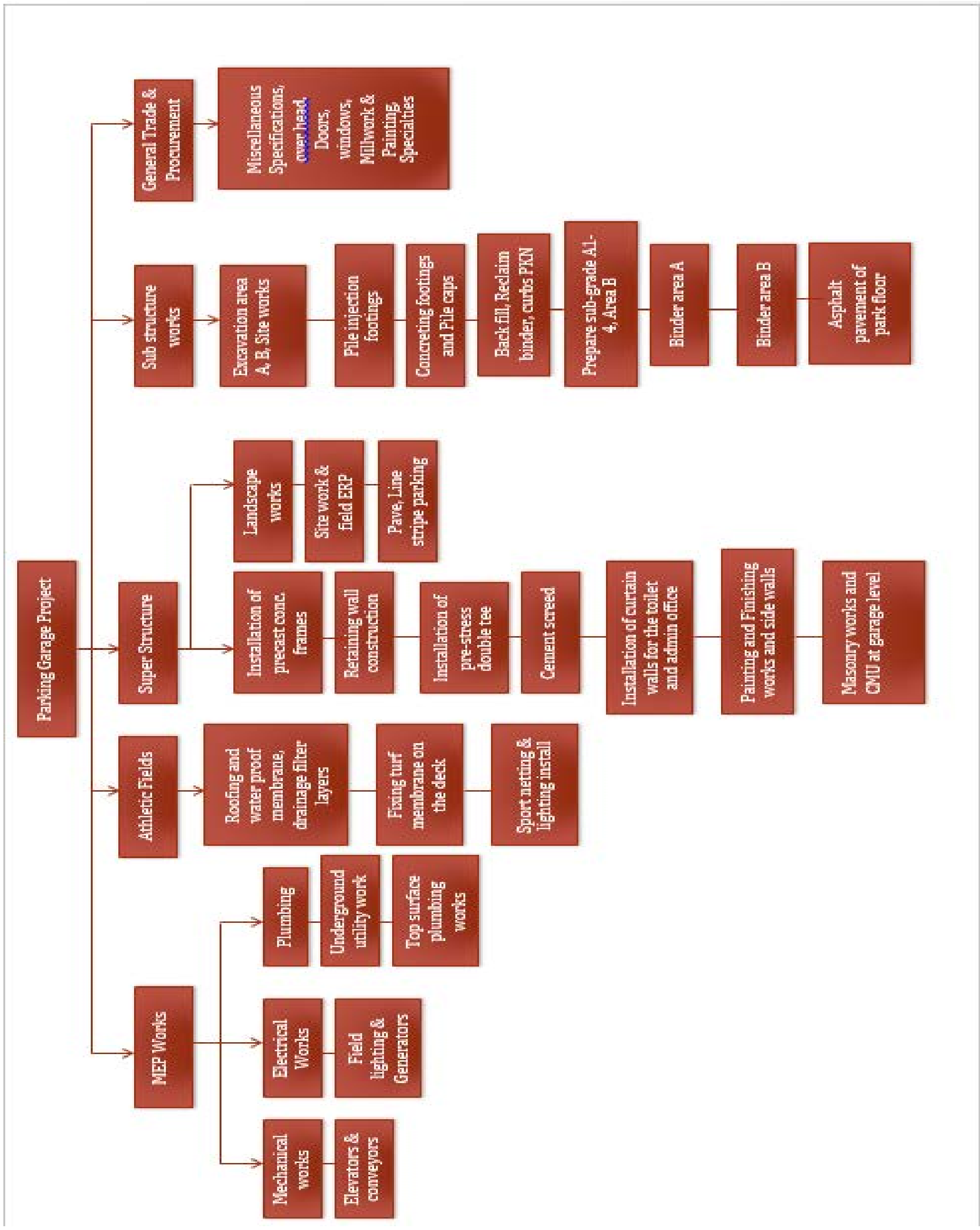


Figure 24 Parking Garage Work Breakdown Structure

No#	Task Name (Work Packages with related broken down activities)	Duration days	ES	EF	Budgeted Cost	A. Cost (spent)
1	Excavations,sheeting and site works	64	May,29,2012	AUG./3/2012	4,907,588	4,978,000
1.1	excavate for FTGS Area A sec 1-3					
1.2	Exca.for parking lots,church,wpl temporary site					
1.3	Exca. For PIP area B					
1.4	Exca. For site prop/cleaning / layout					
1.5	PIF"s Area B sec. 6,7,8,4					
1.6	preparation for future road access.					
1.7	preparation for FTGS & wall foundation					
1.8	Exca. For interior sanitary lones					
1.9	Installation of unger ground plubbing					
2	Retaining Wall Construction	110	Jun/6/2012	Nov/7/2012	1,469,124	1,519,000
2.1	Foundation concreting					
2.2	wall concreting (include steel reinforcement) and forms					
3	Curtain wall construction (pre cast units)	70	July/6/2012	oct/12/2012	331,965	229,000
3.1	Fixing in place the pieces of curtain wall					
4	PIF installation contnd.for rest of project	23	July/9/2012	Aug/9/2012	260,399	361,000
5	Mechanical Installation (Install Plumbing)	118	July/10/2012	Dec/21/2012	1,147,042	1,258,900
5.1	Toilet drain pipes @ garage level (U G)					
5.2	Plumbing (R.I) between CMU walls @ garage level					
5.3	R.I.O .H plumb/ SPKL, ground level.					
5.4	Toilet drains, fixtures, pipes @ garage level.					
6	Sports lighting works (civil and Mech)	83	Aug. /6/2012	Dec/6/2012	634,667	634,667
6.1	Install the posts, power cables, testing					
7	Masonry works and CMU	60	Aug. /5/2012	oct/25/2012	197,680	306,480
7.1	Complete CMU wall @ garage level					
8	Miscellaneous Metals	105	Aug/15/2012	Jan/8/2013	109,975	380,000
9	Installation of Pre-cast concrete forms	95	Aug/16/2012	Dec/26/2012	3,800,000	3,723,000
9.1	Detai and caulk precast					
9.2	Double Tee pre-cast roof install					
9.3	cement screed with steel mesh laying out					
10	Asphaltic works of park roads and out side land scape works	45	Aug/21/12	Oct/22/2012	135,000	135,000
10.1	Reclaim Binder, Curbs, PKNG Lot & Church Lot.					
10.2	Subgrade Area A 1 -4 , Then Area B 5- 8					
10.3	site work and field FRP					
10.4	Binder in Area A					
10.5	Binder in Area B					
10.6	Prepare and place SOG @ grade level					
10.7	pavement and line stripe parking					
11	General Trades	66	oct/5/2012	Jan/4/2013	153,046	220,000
11.1	overhead doors,Mill works, Paints & specialities					
12	Electrical Installation	66	oct/5/2012	Jan/4/2013	795,796	800,000
12.1	Electrical @ masonry wall @ garage level					
12.2	Rough in lighting & FA 2nd floor					
12.3	Rough in lighting # GF					
12.4	Install Lighting CMU Area @ garage Level					
13	Painting	25	Nov/2/2012	Dec/6/2012	122,489	21,000
14	Roofing and water Proof membrane layingout @ all Concrete surfaces. (stairs,roof deck)	15	Nov/16/2012	Dec/06/2012	213,200	205,000
15	Install Field Turf on deck	25	Nov/16/2012	Dec/20/2012	637,000	637,000
16	Fix Frames & Hang doors,Handwares 2 garage level, Toilet partition	25	Nov/26/2012	Dec/31/2012	40,000	40,000
17	Elevators Installation and Testing	20	Dec/10/2012	Jan/4/2013	80,000	62,000
18	Fencing, lighting,and handinoverof parkinh garage only	20	Jan/ 2/2013	Jan/29/2013	161,750	600,000
19	Handing over of Late finished Athletic Field Water proofing Material and Synthetic Turf		May/13/2013	May/28/2013	15,196,721	15,410,047

Table 9 Parking Garage Data for EVA & ES Analysis

After WBS was set, the scheduling of activities (work packages) was conducted using Microsoft Project 2013 software Figures 25 and 26 show Gantt charts for on time and late completions respectively.

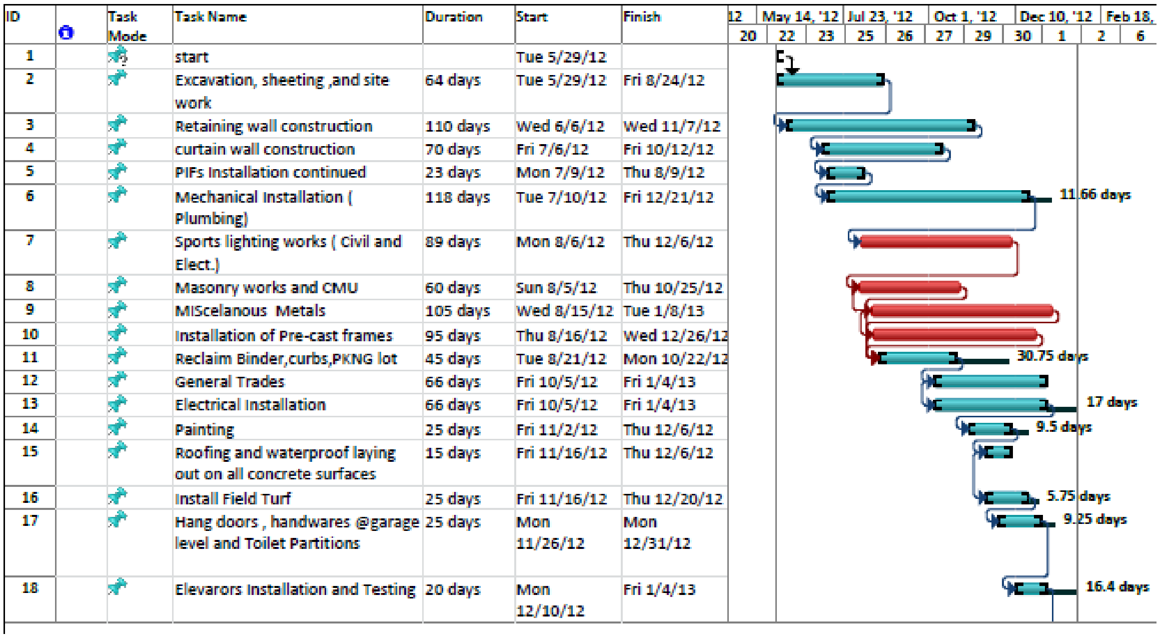


Figure 25 Gantt Chart on time completion

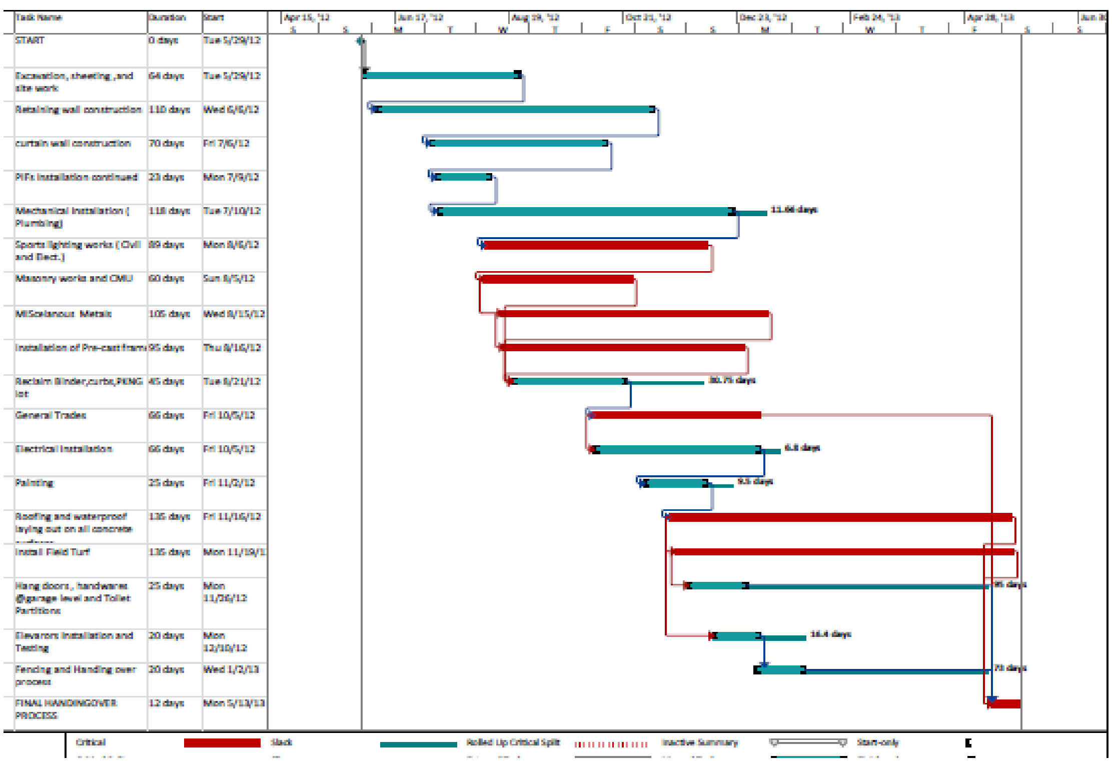
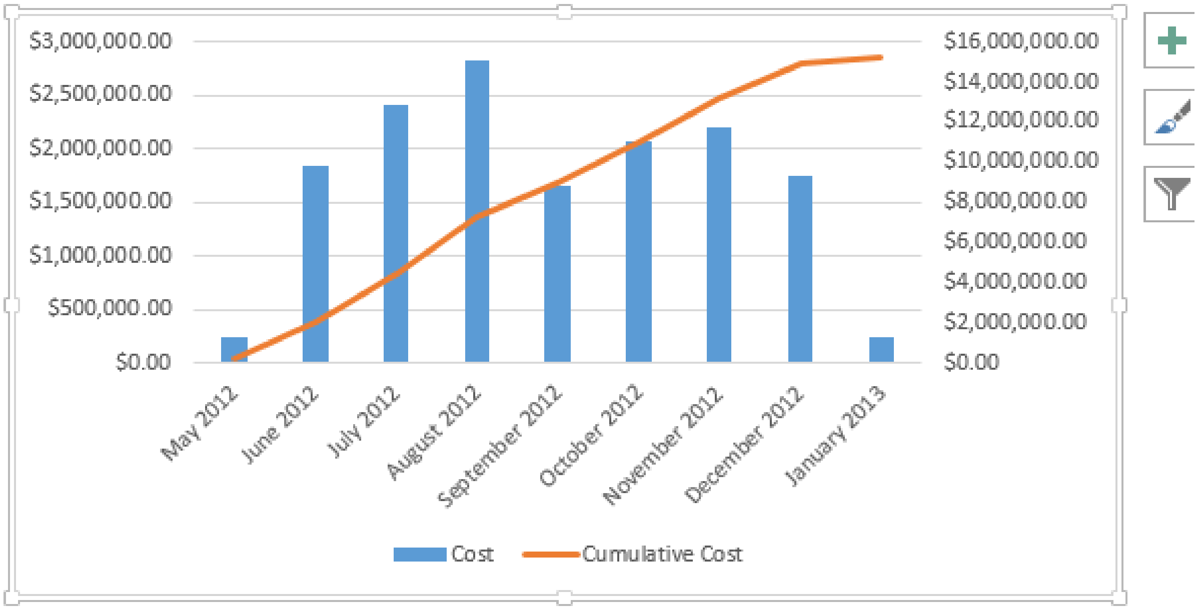


Figure 26 Gantt chart late completion

Figures 27 & 28 display the S-curves for BCWS and ACWP for the on time completion and late completion respectively



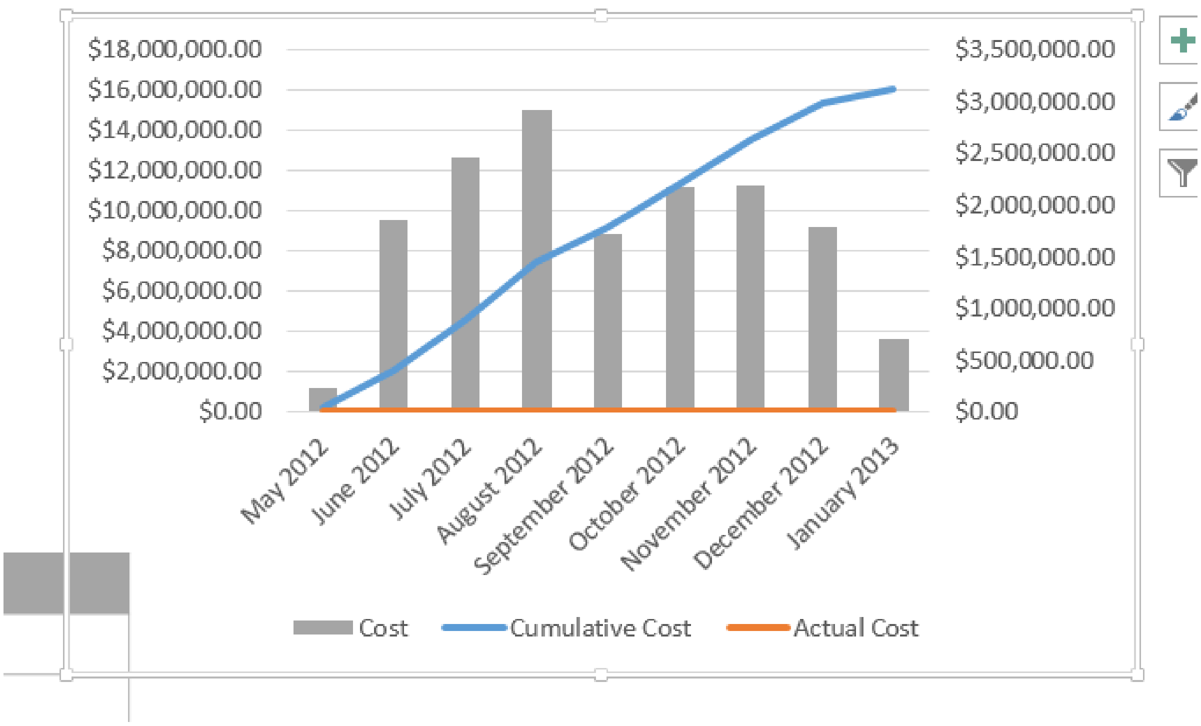
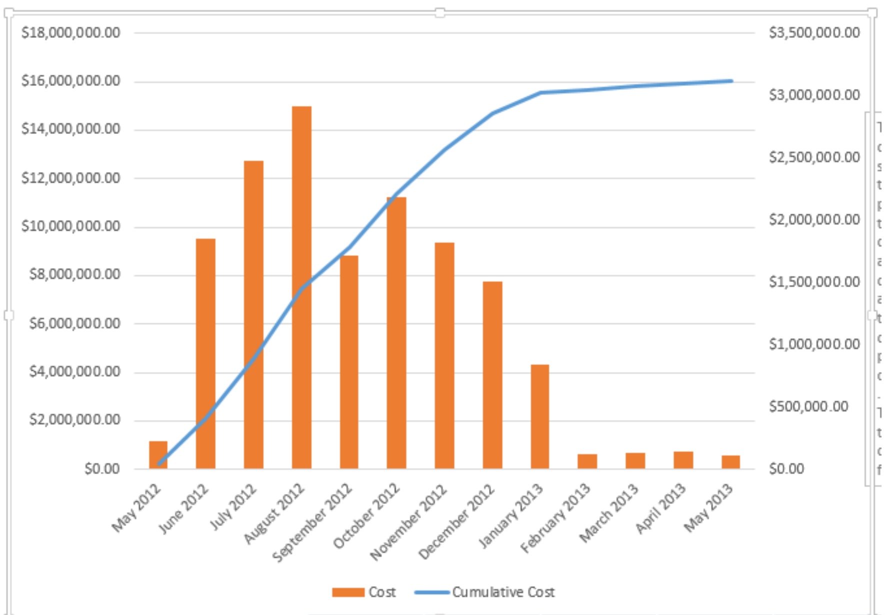


Figure 27 on time completion S-Curves for Budgeted Cost and Actual Cost



Name	Start	Finish	% Complete	Late Finish
P Ga late excuation.mpp AC	Tue 5/29/12	Tue 5/28/13	0%	Tue 5/28/13

Figure 28 Late completion S-Curves for Budgeted Cost and Actual Cost.

The above curves were generated by Microsoft Project 2013

4.3.2 Earned Value Calculation

The target is to quantify the earned value of work done for each month of work progress represented in figure (28) of late completion of the same schedule. The Budgeted Cost of Work Performed (BCWP) is usually calculated by one of the previously mentioned BCWP equations listed in Chapter 2 such as;

$$BCWP = \% \text{ complete} \times BAC$$

Where: Percent complete = (Budgeted units – Units to complete) / Budgeted units.

By this Equation, the BCWP is measured as milestones. However, by examining the behavior of S-curves for Budgeted cost and Actual cost Figure (28) and reading the projected values of cumulative monthly cash flows on vertical axis on any interval of time, one can find that the progressive curve of ACWP is almost identical to the BCWS curve (with a very small gap) which means the work (or the payments were made as projected) was progressing as budgeted costs. So, that gap (time difference in terms of money) could be considered having no influence, and could be ignored in project management, (Mubarak 2010).This means that the (BCWP) of work in progress is the same as (ACWP) indicating to the owner that the budgeting is adequate.

So, one can infer that BCWP = ACWP. This embodies the essence of GMP contract implementation by both the contractor and the owner, i.e., (no savings made from hard cost).

Now, we have two sets of values:

1. Cumulative Budgeted Costs as of BCWS.

2. Cumulative Cost (ACWP) as a (BCWP) for each time interval of project Planned Duration (PD).

From these two sets of values, the EVA and its extension ES parameters (Indicators and cost variances) are derived / calculated as shown in the following table 10. By comparing the calculated or forecasted IEAC resulted from both methods [EVA and ES] with basic CPM duration or the Baseline Planned Duration (PD), a range of time variations from these two methods visually and quantitatively are noticed. The realistic one that better represents the actual time consumed by the project to get completed would be considered as the true total project duration. It also shows which indicator is more reliable to be adopted for tracking and calculating (forecasting) the IEAC of the project. (has no convergence to One at the end of the project, and behaves analogous to CPI trend). Keeping in mind that the CPM course of activities has not been changed during the construction phase.

Below is the actual numerical values used in determination of Earned Value and Earned Schedule indicators of case study project lifecycle.

EVA calculations (May 2012)

Considering Month (May 2012), the data is PV cum = \$ 500,000 and EV cum = \$ 480,000

% Complete = 480000 / 15196721 * 100 = 3.15 %

$SV_{\$}$ = BCWP – BCWS, 480000 – 500000 = - \$ 20000

$SV_{\$}$ % = SV / BCWP, - 20000 / 480000 = - 0.004 %

SPI\$ = BCWP / BCWS = 0.960

IEAC = PD / SPI \$, 9/ 0.960 = 9.375 Month.

ES calculations (May 2012)

I = ($BCWP_{May}$ – BCWS) / ($BCWS_{May}$- BCWS) , (480000 – 0) / (500000 – 0) = 0.96

ES = 0+ 0.96 = 0.96

SV_t = ES – AT, 0.96 – 1.0 = - 0.04 Month. late,

SPI_t = ES / AT, 0.96 / 1 – 0.96

$IEAC_t$ = PD / SPI_t, 9 / 0,96 = 9.375 Month.

EVA calculations (June 2012)

Considering next month (June 2012), the data is BCWS cum = $2,000,000 and BCWP cum = $ 1,940,000

% Comp. = 1940000 / 15196721 *100 = 12.76 %

$SV_\$$ =BCWP – BCWS, 1940000 – 2000000 = - $ 60000

$SV_\$$ %= 60000 / 1940000 * 100 = 0.003 %

$SPI_\$$ = BCWP / BCWS, 1940000 / 2000000 = 0.970

IEAC = PD / $SPI_\$$ 9 / 0.970 = 9.278 Month.

ES calculations (June 2012)

I = ($BCWP_{Jun}$ – $BCWS_{May}$) / ($BCWS_{Jun}$ – $BCWS_{May}$), (1940000 – 500000) / (2000000 – 500000) = 0.960

ES = c + I, 1+ 0.960 = 1.960

SV_t = ES – AT, 1.960 – 2 = -0.04 Month. Late

SPI_t = ES / AT, 1.960 / 2 = 0.980

$IEAC_t$ = 9 / 0.980 = 9.180 Month.

The same procedures could be continued to calculate the EVA and ES parameters of other months till January 2013 which is the last month of the planned schedule duration,

EVA calculations (January 2013)

BCWS cum = $ 15196,721 BCWP cum = $ 14,550,000

% Comp. = 14550000 / 15196721*100 = 95.57 %

$SV_{\$}$ = BCWP – BCWS,   14550000 – 15196721 = - \$ 646,721

$SV_{\$}$ % = - 646,721 / 14,550,000 *100 = - 4.5 %

$SPI_{\$}$ = BCWP/ BCWS,   14550000 / 15196721 = 0.957

IEAC = PD / $SPI_{\$}$ 9 / 0.957 = 9.4 MON.

ES calculations (January 2013)

I = ($BCWP_{Jan}$ – $BCWS_{Dec}$) / ($BCWS_{Jan}$ – $BCWS_{Dec}$),

I= (14550000 – 14300000) / (15196721 – 14300000) = 0.278

ES = C + I,   8 + 0.278 = 8.278 Month.

SPI_t = ES / AT,   8.278 / 9 = 0.9197

$IEAC_t$ = PD / SPI_t ,   9 / 0.9197 = 9.785 Month.

The Calculation continues for delayed time execution considering Feb. 2013

EVA calculations (February 2013)

Here BCWS ~ BAC much earlier than BCWP approaches BCWS on the Baseline, and we have no more $BCWS_{cum}$ values on the Baseline planned duration while $BCWP_{cum}$ still achieving incremental values with time from work remaining.

So, using % Comp. equation to calculate the performance of project during the late completion time.

BCWS cum = \$ 15,196,721   BCWP cum = \$ 14,711,680

% Comp. = 14711680 / 15196721 *100 = 96.80 %

$SV_{\$}$ = BCWP – BCWS   14711680 – 15196721 = - \$485,041

SV % = - 485041 / 14711680*100 = - 3.2 % (Deviation)

$SPI_{\$}$ = BCWP / BCWS,   14711680 /15196721 = 0.968

IEAC = PD / $SPI_{\$}$ 9 / 0.968 = 9.300

ES calculations (February 2013)

ES = 96.8 / 100 * 9 = 8.712 Month.

$SV_t = ES – AT$,   8.712 – 10 = - 1.287   Month. late

$SPI_t = ES / AT$,   8.712 / 10 = 0.871

$IEAC = PD / SPI_t$ 9 / 0.871 = 10.33   Month.

The calculation procedure is similar for the next months March and April 2013. For the month of May 2013

EVA calculations (May 2013)

BCWS cum = BAC = $ 15,196,721

BCWP cum = BCWS cum = BAC = $ 15,196,721

% comp. = 100 %

SV $ = 0,   SPI $ = 1,   IEAC = PD /SPI $,   9 / 1 = 9 Month. (meaningless)

ES calculations (May 2013)

ES = 9 (mon)

SV t = ES – AT,   9 – 13 = -4 Month. late

SPI t = ES / AT,   9 / 13 = 0.692

IEAC t = PD / SPI t,   9 / 0.692 = 13   mon. which is realistic, meets the Baseline/ (CPM).

The calculations for the entire project under both methods are summarized in Table 10

	May-12	June	July	Aug	Sept.	Oct.	Nov.	Dec.	Jan-13	Feb	Mar	Apr	May
PC Percent	3.15%	12.76%	26.97%	46.00%	57.25%	72.38%	84.22%	91.73%	95.57%	96.80%	97.87%	98.90%	100%
BCWS (PV) cum	500,000.00	2,000,000.00	4,100,000.00	7,000,000.00	8,700,000	11,000,000	12,800,000	14,300,000	15,196,721	0	0	0	0
BCWP (EV) cum	480,000.00	1,940,000	4,018,000.00	6,825,000	8,600,000	10,560,000	12,288,000	13,940,000	14,550,000	14,711,680	14,873,360	15,035,040	15.196,721
SV ($)	-20	-60	-82	-175	-100	-440	-512	-360	-646,721	-485,041	-323,361	-161,681	0
SV%	-0.004	-0.003	-0.002	-0.0025	-0.0014	-0.004	-0.004	-0.0036	-4.50%	-3.20%	-2.12%	-1.06	0
SPI ($)	0.96	0.97	0.98	0.975	0.988	0.96	0.96	0.974	0.957	0.968	0.978	0.989	1
IEAC (=PD/SPI)	9.375	9.278	9.183	9.23	9.109	9.375	9.375	9.24	9.4	9.3	9.195	9.096	9
AT	1	2	3	4	5	6	7	8	9	10	11	12	13
ES	0.96	1.96	2.96	3.939	4.941	5.808	6.716	7.76	8.278	8.71	8.8	8.9	9
SV(t)	-0.04	-0.04	-0.04	0.061	-0.059	-0.192	-0.284	-0.24	-0.72	-1.287	-2.191	-3.095	-4
SPI(t)	0.96	0.98	0.986	0.985	0.988	0.968	0.956	0.97	0.919	0.871	0.804	0.741	0.692
IEAC(t)	9.375	9.18	9.127	9.137	9.109	9.297	9.414	9.278	9.78	10.33	11.18	12.134	13

SV($) =EV-PV	ES= C+I	SV(t) = ES-AT
SPI($)= EV/PV	I=(EV-PVt)/PV(t+1) - PV(t)	SPI(t)=ES/AT
IEAC($)= PD/SPI($)	C= No of entire periods (month)	IEAC(t)=PD/SPT(t) for the case when work progressing as planned.

Table 10 Comparison between EVA final duration forecast vs. ES final duration forecast.

The resulting SVt and SPIt for each month are plotted in Figure (29) below

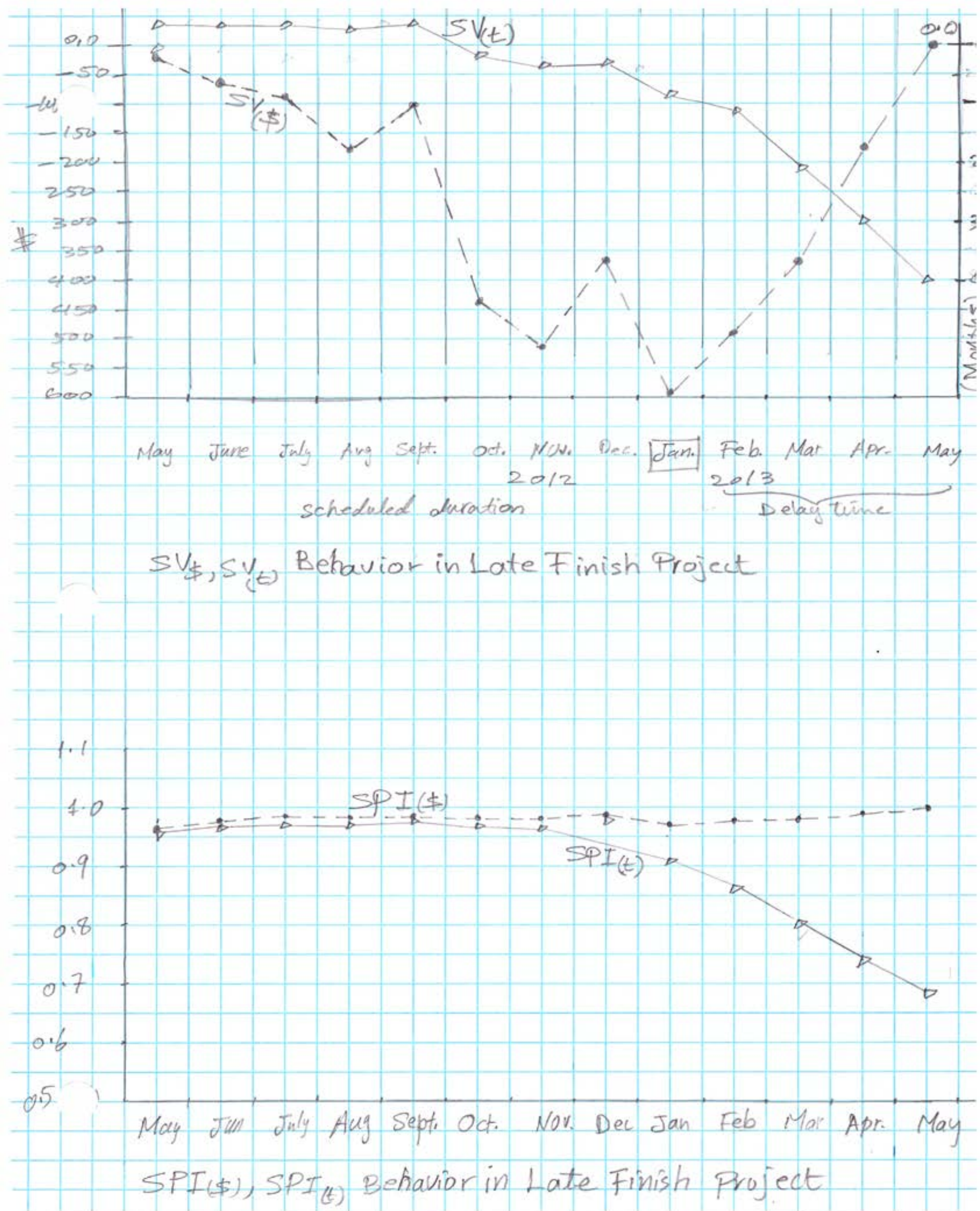


Figure 29 Comparison of Performance Indices SV$ vs. SVt and SPI$ vs. SPIt

4.3.3 BIM Integration

The BIM model was created with Revit 15 Architectural and Structural tool. This software program allows to accurately create a 3D model of the structure of the parking garage. The model was The model was created using: 1) the precast structural subcontractor BIM model, 2) 2D construction shop drawings and sketches, 3) information and documentation provided by the design-builder for this project. The Model was developed at a level of development (LOD) 300 in which Model elements are modeled as specific assemblies which are accurate in terms of quantity, size, shape, location. This level is similar to Design Development. It included objects for the majority of the bid packages. The time schedule was provided by the contractor in pdf format and it served as a guide to create a new time schedule using critical path method software (Microsoft project 2013).

3D model

The Revit Structural model started by setting up the different levels and grid lines. The grid lines, which mimicked the structural drawings gridlines, were used to help provide a reference for the different aspects of the structure. The attached 2D drawing, Figure (30) shows the plan view of the garage level of the model with grid lines. Levels depict each different floor in the structure. The levels included the subfloor or soil level. Level one which is the garage level, and the second level which shows the athletic fields. These boundaries set up the basis for creating the structural components of the building. As there are varying soil conditions throughout the base of the garage, both deep and shallow foundations had to be used (size and shape chosen identical to 2D drawings provided by the prime contractor). The piles were inserted at each gridline intersection, similar to the architectural drawings. In areas where there was bedrock closer to the surface, footings with a smaller surface area were used. While pressure Injected Footings (PIFFs) had been used to reach the deeper depths where the soil layers had a lower bearing capacity. The foundation was then finished by adding a foundation wall on the perimeter to help support the interior structural shearing walls. A compacted backfill and a two-binder asphalt layer were laid down on the top of the footing. Fig. (31) shows 3D rendered image of a deep foundation piles under the foundation floor from the BIM model. After the foundation was solidly built, the main components of the garage were added. This started by putting columns on the garage level. For maximum ventilation, much of the garage level was left open and walls were erected in only two of the four sides of the parking garage. On the other side of the structure, steel girders were placed up against the edge of the garage to support the upper level. Then precast concrete I beams were inserted and double Tee beams as well as the girder to support the roof structure of the garage ending the superstructure construction main components

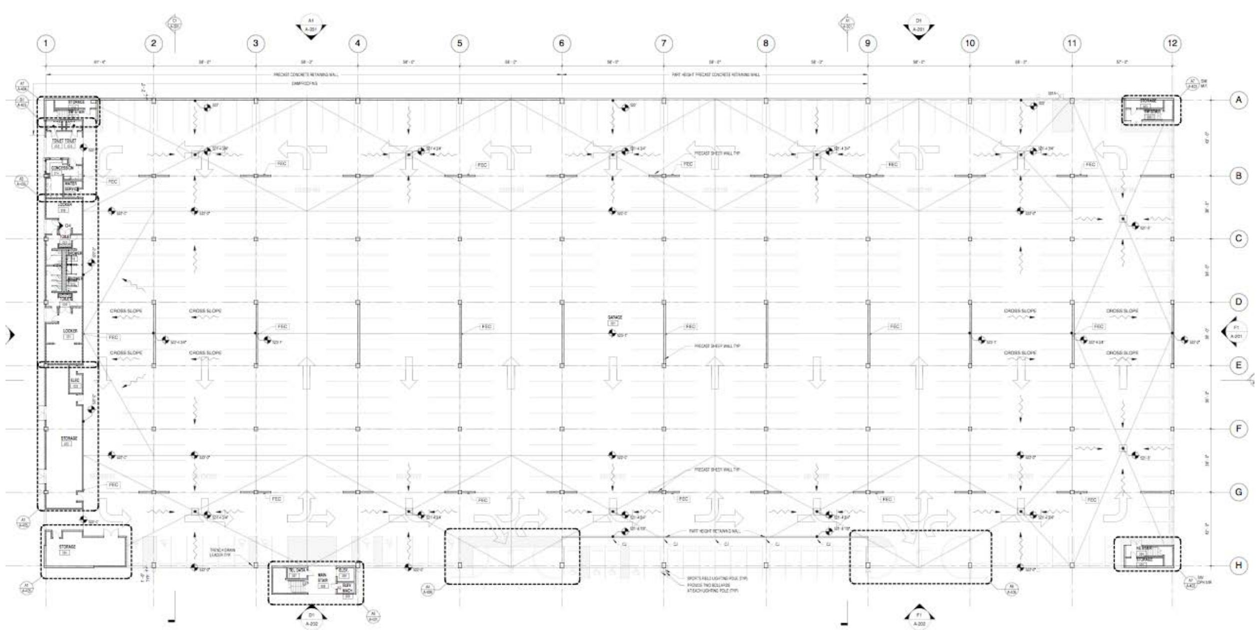


Figure 30 Parking Garage Plan View

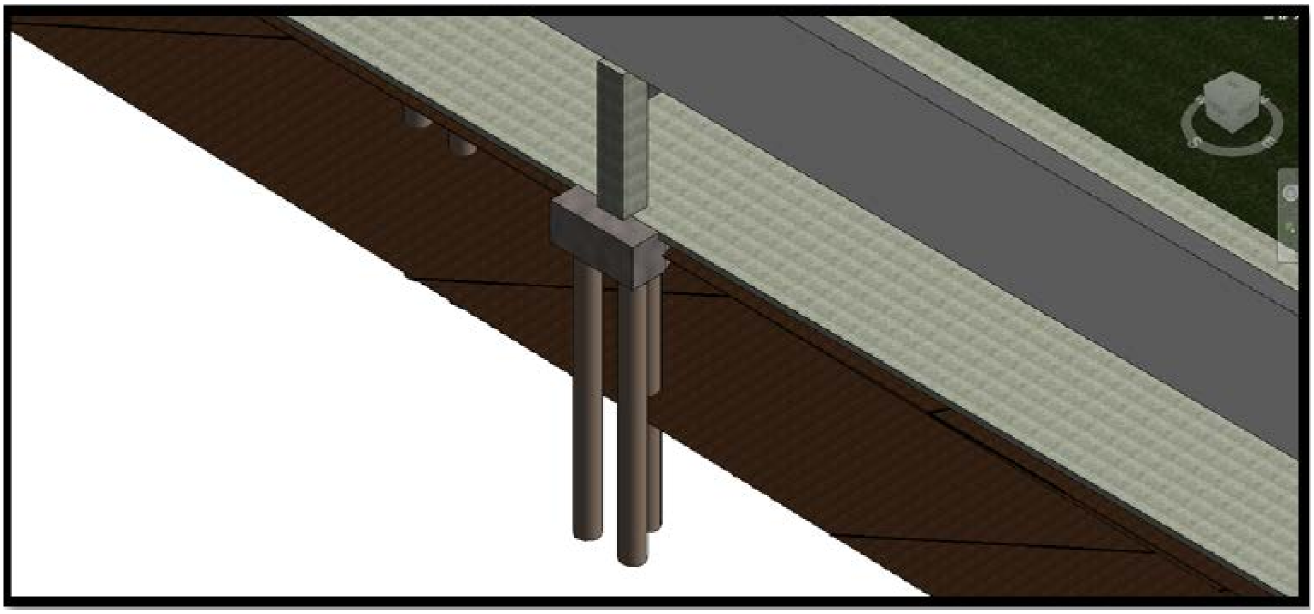


Figure 31 3D model of piled deep foundation (Alvarez & Gomez 2013)

Later on, in the project certain circumstances came into play. The school expected the project to be completed in early January 2013 without getting deep into the winter months weather. The main problem with cold weather was that the synthetic turf could not be sewn on the field if the temperature was less than 45 degree Fahrenheit. This was a major challenge since it is a five week process that was originally scheduled to take place in early December. As construction progressed into the latter part of the schedule, it was determined that the most practical option was to have parking garage completed by the early January, 2013 as originally planned but the athletic turf should be executed in late in the spring under warmer weather conditions and complete the project As of January 2013 until May 29, 2013. (Actual completion date) .So, the project has recorded four months delay upon the pre- approval of the owner.

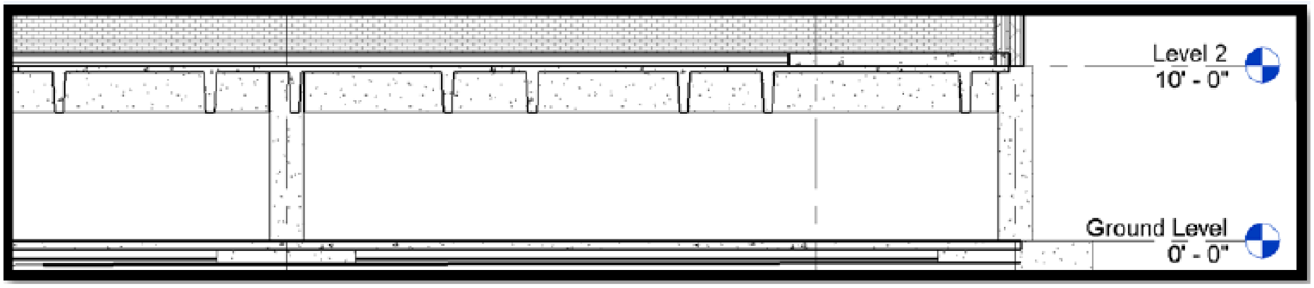


Figure 32 Precast Double Tee Roof concrete slab (Alvarez & Gomez 2013)

The athletic field was built with a combined set of layered materials including cement screed mortar reinforced with steel mesh was put in place as a base. Then followed with water proof membranes and two layers of graded gravel to work as water drainage under the synthetic turf. These layers were modeled by adding a floor with multiple layers. These layers included a sub base, filter fabric gravel, sand and a top layer of grass as seen in the Figure 33. Outside the turf there were two sidewalks that run the length of the field

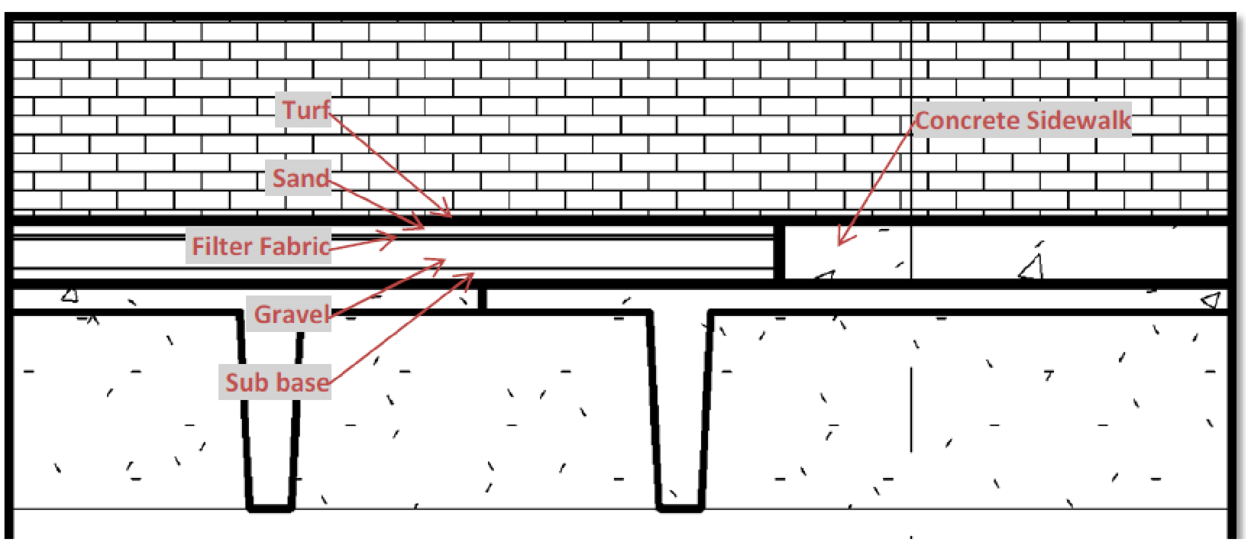


Figure 33 layered system for the athletic field (Alvarez & Gomez 2013)

4D model

A 3D model can be phased to display the gradual progress of construction. A 4D model list generated when each phase is combined with the actual dates of execution of that phase where the complete shape, materials, and quantification are made available at that phase. This 4D model is created by integrating Microsoft Project 2013 modified scheduled work packages with the 3D BIM model components (sub-structure and super structure) that was originally scheduled to handing over in early January 2013. But as mentioned earlier, due to bad weather condition encountered the layout of synthetic turf, the schedule has been modified to end on May 2013. Therefore, by inputting the modified project schedule (Finish-Start relationships) for late completion, we can view each major construction milestone in the form of time phased - cost as it was being built. Figures (35 & 36) below represent different phases of the 4D model. This action helps the subcontractors to check their models before/during construction course for clashes if any. Moreover, the owners need to visualize the changes happened at site and track the progress of work with associated cash flow and to arrange mitigating any risks may arise with financial institution funding the project. Now each viewed specific phase could be superimposed to the Project Management Baseline or S-curve of project that was developed by EVA and ES as shown in Figure (37) to get the full integrated benefit of utilizing BIM with EVA and ES method for involved stakeholders to track the time and cash flow performance of project. This is the missing link through which the owners, contractors and all stakeholders can make effective implementation of how BIM tools could be merged with EVA and ES to track the progress of project.

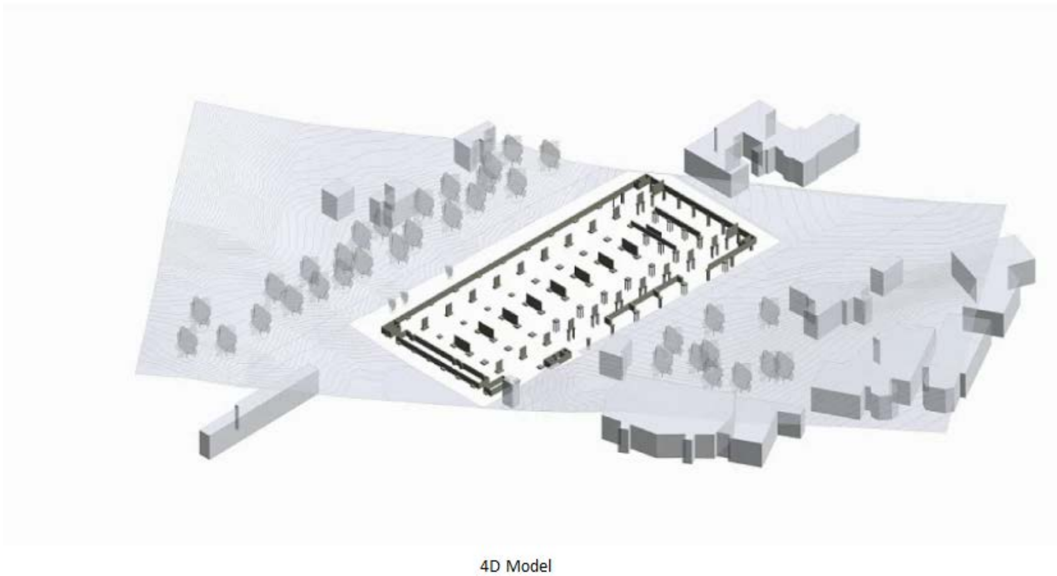


Figure 34 4D model of construction progress (Abdulahad & Zabeti 2014)

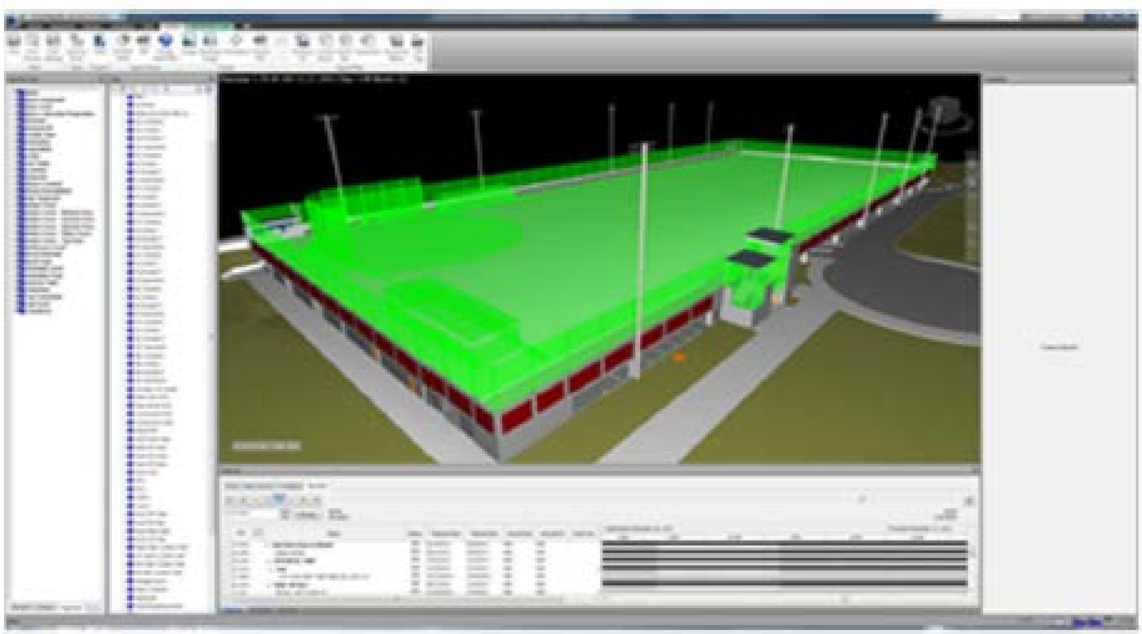


Figure 35 4D model (Alvarez & Gomez 2013)

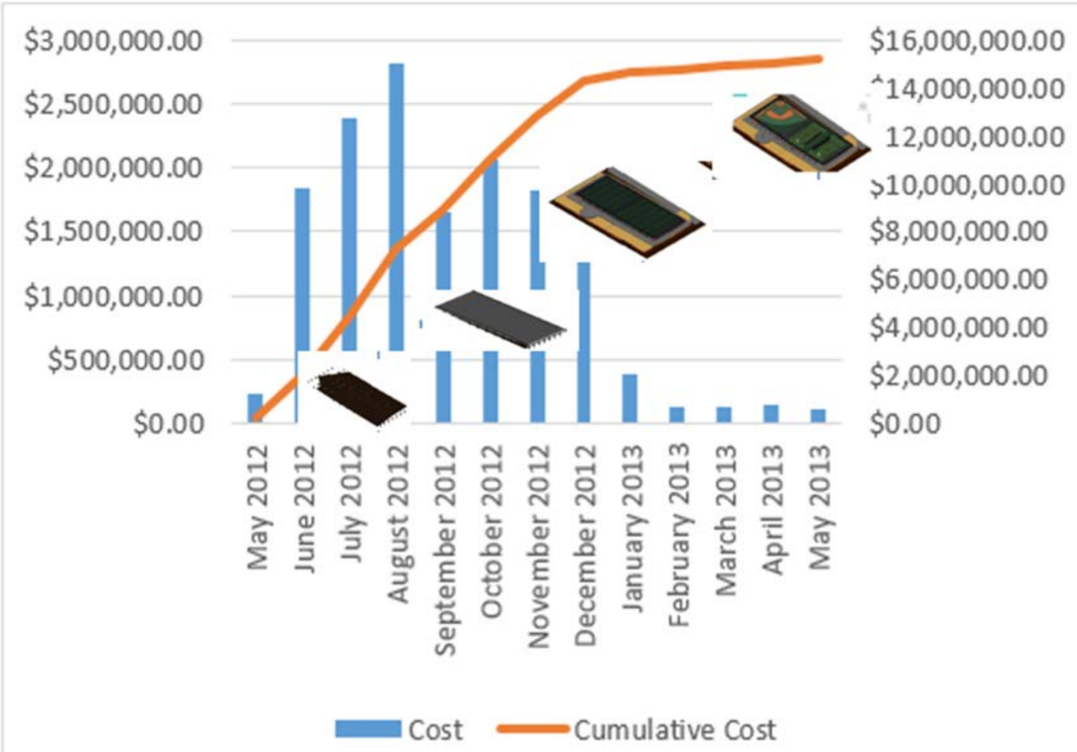


Figure 36 Time Cost & Scope Integration (Abdulahad & Zabeti 2014)

4.4 Case Study Results and Outcomes

The following are the main results and outcomes derived from this case study

1. The research shows that the Schedule Variance SVt (-4) which means (4) months late is realistic, while EVA Schedule Variance $SV_{\$} = 0$, and Schedule Performance Index $SPI_{\$}$ converges to 1.0 . The $SPI_t = 0.692$ (at month 13) means a deviation of 30% from planned schedule had been taken place.
2. Earned Schedule shows that total project forecasted duration Indicator IEACt is (13) months while Earned Value Indicator IEAC still shows (9) months only. Which is unrealistic, thus misleading the owner expectations as to the date of completion and preventing early discussion about the impact of a delay.

3. Earned Schedule (ES) Indicator $IEAC_t$ for total duration is found to be identical to the critical path method (CPM) duration or Baseline Planned Duration (PD), more accurate than EVA, and directly correlated to it.
4. When two values of $SPI_\$$ and SPI_t are found equal to each other exactly, planned and actual performance of work progress are also equal on that period of time. (This is happened only one time).
5. Earned Schedule (ES) measures the time in units of time (days, weeks, months), while EVA makes assessment of time performance based on dollar value or cost value, which makes it difficult to interpret, and match the variance with CPM of the project.
6. Earned Schedule (ES) could be applied on any time interval of project life-cycle, and not only to the whole project duration which makes it very effective to track the schedule performance of the project.
7. Earned Schedule (ES) more often eliminates the formation of gray time area at 70 -80 % completion (assessment distortion).
8. The work presented in this study allowed the researcher to explore the practical and educational implications of using BIM models incorporated with Earned Value Management Method in different aspects of design and construction process at WPI. The researcher found that ;
   - BIM is a great way to visualize different design options .These models should be used more often in design –build projects to help the client understand what the different options will look like instead of trying to imagine them.
   - BIM can be used as a way to check estimates by quantifying the material from the model.

- BIM can track the project milestones in phases to help foresee the progress of project throughout construction.
- 5D model explicitly displays the dynamic correlation among the three variables Scope- Time and Cost in a clear visual fashion facilitating the understanding of the impact that each variable has on the other two variables as well as on the communication among the project participants.
- The creation of the LOD 300 model brought out several modeling issues mainly with regards to ;
  - Interoperability.
  - Extraction of information from 2D drawings design implications.
  - Construction simulation.
  - Fully integrated 5D and 6D modeling
  - Better understanding and control of granularity (LOD) in the modeling.
  - Granular Contains Transference of Experience to course and project work (Construction Project Management and BIM courses).

Chapter 5 Final Conclusions and Recommendations

The following overall conclusions are derived from this study

1. Earned Schedule (ES) could be applied at any stage to assess the progress of work at any time interval and not only to forecast the entire project duration, in units of time.
2. Earned Schedule (ES) uses the same data of Earned Value Analysis (EVA) concept, so it could be considered as an extension of EVA.
3. Earned Value Analysis (EVA) fails to give accurate / reliable Schedule Performance terms for late completion projects, while it is accurate only for Cost performance terms, (CV and CPI).
4. Due to its accuracy, and realistic results, ES should always be used in conjunction with EVA to assess Schedule Performance in order to protect the rights of owners to claim for unjustified delay by the contractor(s) if any, and to seek the fair allocation when “liquidated damages” clauses exit in the contract.
5. Recommendation; Specific to this study, $SPI_{\$}$ was figured to be already floated from the beginning of the project and not a correct indicator(forecaster) up to 15% completion, which need to be verified by further study.
6. Further BIM research need to be conducted using BIM such as Navisworks software to solve the very congested fast track schedule to create more realistic 4D simulation.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACWP	ACTUAL COST OF WORK PERFORMED
ANSI	AMERICAN NATIONAL STANDARD INSTITUTE
AT	ACTUAL TIME
AT&L	ACQUISITION, TECHNOLOGY AND LOGISTICS
ATE	ACTUAL TIME EXPENDED
BIM	BUILING INFORMATION MODELING
BAC	BUDGET AT COMPLETION
BCWP	BUDGETED COST OF WORK PERFORMED
BCWS	BUDGETED COST OF WORK SCHEDULED
BCWSav	AVERAGE COST OF WORK SCHEDULED
BCWSCum	CUMULATIVE COST OF WORK SCHEDULED
CPM	CRITICAL PATH METHOD
CPR	CONTRACT PERFORMANCE REPORT
C/SCSC	COST/SCHEDULE CONTROL SYSTEM CRITERIA
DID	DATA ITEM DESCRIPTION
DoD	DEPARTMENT OF DEFENCE
ES	EARNED SCHEDULE
EVA	EARNED VALUE ANALYSIS
EVav	AVERAGE EARNED VALUE
Evcum	CUMULATIVE EARNED VALUE

EVM	EARNED VALUE MANAGEMENT
EVMIG	EARNED VALUE MANAGEMENT IMPLEMENTATION GUIDE
EVMS	EARNED VALUE MANAGEMENT SYSTEM
FD	ACTUAL FINAL DURATION
IEAC(t) EV	INDEPENDENT ESTIMATE AT COMPLETION - EV method
IEAC(t) ES	INDEPENDENT ESTIMATE AT COMPLETION - ES method
IMS	INTEGRATED MASTER SCHEDULE
PD	PLANNED DURATION
PMB	PERFORMANCE MANAGEMENT BASELINE
PV	PLANNED VALUE
SPI	EVA SCHEDULE PERFORMANCE INDEX
SPI(t)	Earned SCHEDULE PERFORMANCE INDEX
WBS	WORK BREAKDOWN STRUCTURE
WR	WORK RATE