

Tutorial on Earned Value Management Systems

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1.0 Overview

1.1 Background

In the midst of a typical project, it is often desirable to estimate such quantities as "how much time is left?" or "how much of the work is complete?" or "how much money will the project spend before it is complete?" If these remind you of trips in the family car where the children are wondering "are we there yet?", it is not surprising. Just as the passengers on a trip wonder how long it will take to get to the destination, so managers have a responsibility to understand how long a project will take to get to its destination - and what it will cost. Those working on the project usually want to know this too.

Earned Value Analysis (EVA) is a way to measure the amount of work actually performed on a project (i.e., to measure its progress) and to forecast a project's cost and date of completion. The method relies on a key measure known as the *earned value* (also known as the "budgeted cost of worked performed" or BCWP). This measure enables one to compute performance indices for cost and schedule, which tell how well the project is doing relative to its original plans. These indices also enable one to forecast how the project will do in the future.

Earned value actually uses three data values, which are computed each week, month, or whatever other period you wish to use. We use the term "analysis date" to refer to the date when the three values are analyzed. Thus if we measure these values monthly, an analysis date of October 31 would include all values from project inception until the end of October.

The three values are:

- Budgeted Cost of Work Performed (**BCWP**).
- Budgeted Cost of Work Scheduled (**BCWS**).
- Actual Cost of Work Performed (**ACWP**).

1.2 Definition of the Three Basic Values

BCWP or Budgeted Cost of Work Performed or **Earned Value**

This is the cost originally budgeted to accomplish the work that has been completed as of the analysis date. It answers the question "how much work has actually been completed?".

BCWS or Budgeted Cost of Work Scheduled or **Plan**

This is the total budgeted cost up to the analysis date. It answers the question "how much did we plan to spend as of this date?" A variant of this question is "how much work should have been completed by this date?" BCWS can be computed from the project's plans, as illustrated in the sequel, or it can be approximated by multiplying the total budget by the fraction of total project duration at the analysis date. Thus, for example, if the project budget is \$100 and 20% of the project's time has elapsed, the approximate BCWS is \$20.

ACWP or **Actual** Cost of Work Performed

This is what it actually cost to accomplish all the work completed as of the analysis date. It answers the question "how much have we actually spent?". This is usually determined from the organization's accounting system, or can often be approximated by multiplying the number of people by the number of hours or days or weeks worked.

1.3 Derived Metrics

Four measures can be computed from the basic values described above:

- Schedule Variance (**SV**) = $BCWP - BCWS$

If it is 0, you are right on schedule. If it is negative, you are behind schedule. If it is positive, you are ahead of schedule.

- Schedule Performance Index (**SPI**) = $BCWP / BCWS$

If it is 1, you are right on schedule. If it is less than 1, you are behind schedule. If it is greater than 1, you are ahead of schedule.

- Cost Variance (**CV**) = $BCWP - ACWP$

If it is 0, you are right on budget. If it is negative, you are over budget.
If it is positive, you are under budget.

- Cost Performance Index (**CPI**) = $BCWP / ACWP$

If it is 1, you are right on budget. If it is less than 1, you are over budget. If it is greater than 1, you are under budget.

2.0 Using EVA to Determine Where you Are

2.1 Units

There are many ways to measure "cost". For example, we could measure actual money spent. However it is common in a work environment to measure cost in terms of *labor* - that is in work hours or work days spent. Thus the budget for a project could be \$30,000 or it could be 300 labor hours, and the amount spent so far could be \$4,500 or it might be 45 labor hours. EVA can be used with any measure of cost, but it is important to decide which one to use. We will use an example in dollars in this section and an example in work days in the sequel.

2.2 An Example using Dollars

Suppose you are making cookies for a large party to be held tomorrow. Suppose the following are your plans:

Plans:

- 40 cookies per batch
- 5 batches per hour (200 cookies)
- Schedule: 5 hours to make a total of 1000 cookies
- Budgeted cost per cookie is \$0.05
- Total budget is \$50.00 for cookie ingredients, or \$10 per hour

We'll use earned value to examine our progress.

Progress Report at End of Hour 1:

- 150 edible cookies have been made (some were burnt and had to be thrown away)
- Total actual cost of ingredients used so far is \$9.00 (ACWP)

Analysis:

$$BCWS = \$10.00$$

$$BCWP = \$7.50 \text{ (Earned Value) [150 cookies} \times .05 \text{ per cookie]}$$

$$ACWP = \$9.00 \text{ [from above]}$$

Therefore:

$$SV = BCWP - BCWS = -\$2.50 \text{ (you are behind schedule)}$$

$$SPI = BCWP / BCWS = 0.75 \text{ (you are running at 75\% of the planned schedule)}$$

$$CV = BCWP - ACWP = \$7.50 - \$9.00 = -\$1.50 \text{ (you are \$1.50 over budget)}$$

$$CPI = BCWP / ACWP = 0.833 \text{ (you are running over budget by about 17\%)}$$

3.0 Using EVA to Forecast

3.1 Additional Terminology and Definitions

Five additional terms will be used in forecasting:

- **BAC** - **B**udget **A**t **C**ompletion = Total Original Budgeted Cost
This is the same as BCWS at completion
- **EAC** - **E**stimate **A**t **C**ompletion = your estimate of the amount of money you will spend on the project. This is based on your judgment.
- **IEAC** - **I**ndependent **E**stimate **A**t **C**ompletion = Projected final cost of the project, based on performance so far. IEAC can be forecast using the following formula:

$$IEAC = BAC / CPI$$

- **ISAC** - **I**ndependent **S**chedule **A**t **C**ompletion = Projected duration of the project, based on performance so far. ISAC can be forecast using the following formula:

$$ISAC = \text{Schedule} / SPI$$

- **VAC** - **V**ariance **A**t **C**ompletion = Forecast of final cost variance
= BAC - IEAC or, if you prefer, VAC = BAC - EAC

3.2 Forecasting the Cookie Budget and Schedule

$$IEAC = BAC / CPI = \$50 / 0.833 = \$60$$

$$VAC = BAC - IEAC = \$50 - \$60 = -\$10 \text{ (\$10 over budget)}$$

$$ISAC = 5 / SPI = 5 / 0.75 = 6.67 \text{ hours}$$

In other words, you forecast that it will take 6 2/3 hours and \$60 to make the cookies, if your success at making them does not improve. Stripped of all the verbiage, imagine someone telling you "at the rate you are going, it is going to take you all day and it will cost more than you bargained for." EVA enables you to say that in more precise terms.

Perhaps for making cookies, such precision is not essential (although if the prediction was 44 hours, you would have something to worry about!). But for running an expensive project, EVA can be very helpful, even essential.

4.0 Can we Catch Up?

4.1 To-Complete Performance Index

Once we report that our project is behind schedule or over budget, the next question is usually "can we do something to get back on track?" Can we meet the desired schedule and budget despite the fact that we are running behind? Two indices are computed to help determine this. The "To-Complete" performance index is an indication of how we must perform for the duration of the project in order to meet our desired cost goal. If TCPI is greater than 1, we must perform better than planned in order to meet the goal; and if less than 1 we can get by with performing under our plan.

- $TCPI = (\text{Budget}-BCWP) / (EAC-ACWP)$

where EAC is the amount we estimate we will spend. Looking closely we see that the numerator is how much work is left to do and the denominator is how much we have left to spend. Note too that if EAC is simply IEAC, then the TCPI is the same as the CPI - i.e., it indicates that if we do not change our performance, IEAC is the correct estimate of our final cost. (Exercise for the reader: prove mathematically that if $EAC = IEAC$ then $CPI = TCPI$.)

We mentioned two indices. A schedule index can also be developed. (This is left as an exercise for the reader).

4.2 Application to the Cookie Example

In the cookie example, suppose we want to finish at exactly the \$50 budget. Then $TCPI = (50.00-7.50) / (50.00-9.00) = 42.50/41.00 = 1.036$. This means that we must perform at 103.6% of the originally planned performance in order to do this. I.e., 3.6% higher performance than originally planned. This may be

reasonable because we were able to get the first 200 cookies in the oven for only \$9 instead of the budgeted \$10. But if TCPI had been 1.5, we would know that we were in budget trouble unless we can somehow get our supplies at a substantial discount over the plan!

5.0 Using EVA on a Project

5.1 The Micro Schedule - Identifying the Tasks

There are many ways to use EVA on a project, but the method we will illustrate here is one of the easiest and most useful. We begin with a micro schedule - a schedule of small tasks whose duration can be measured in days or weeks. Typically a micro schedule applies to a portion of a project and is estimated by those doing the work, often just before they begin that portion of the project (figure 1).

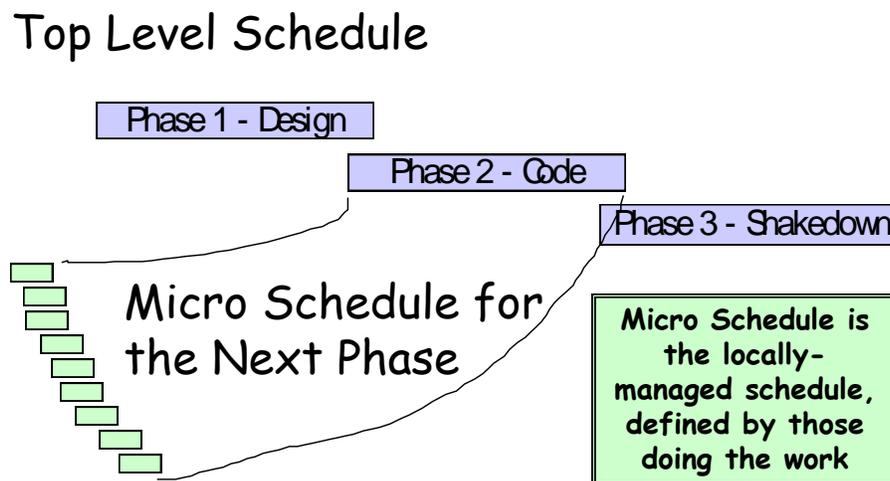


Figure 1 - EVA Micro Schedule

The micro schedule represents the work tasks ("inchstones") required to do the job as well as who is assigned to do each task and their estimates of the effort required. Each task must have

- **objective completion criteria** so you really know when they are done;
- **"budgets" or "values"** (usually represented as person days of effort or dollars of cost);
- **planned completion dates** so you know when you expect them to be done.

Table 1 illustrates a typical micro schedule:

Table 1 - Micro Schedule for Coding Phase, Project XXX

<u>Task</u>	<u>Effort Planned (work days)</u>	<u>Estimated Completion Date (week #)</u>	<u>Responsible Software Developer(s)</u>
Set Up	3	1	Joe
Get Specs	2	2	Mary
Design Output	10	5	Pete & Joe
Plan Tests	3	6	Joe
Write Code	5	7	Mary
Unit Test	3	8	Joe
Integrate	2	9	Mary
Beta Test	3	10	Pete
TOTAL	31		

(The approach illustrated above relies on the judgment of the participants but if the organization is at SEI CMM level 1 or 2, it may not utilize any information from past projects other than the experience of the participants. In an organization at CMM level 3, the micro schedule might be defined by using the organization's (tailored) process. At level 4 or higher, it might be defined by using the process, the judgment of the participants, and past performance data.)

5.2 Computing the Effort Planned (BCWS)

The effort planned is determined by calculating, from the micro schedule, how much work will be completed by the end of each week. Table 2 illustrates a typical BCWS chart.

Table 2 - BCWS for Coding Phase, Project XXX

<u>Week</u>	<u>Total Value that we Plan to Earn by That Week</u>	<u>Shorthand BCWS (Total/week #)</u>
1	3	3
2	5	6
3	7 (*)	9
4	11 (*)	12
5	15	15
6	18	19
7	23	22
8	26	25
9	28	28
10	31	31

(*) Assumes partial progress on "design output" task

5.3 Collecting Earned Value Each Week

Each week during the project, the team needs to indicate, at the end of the week, which tasks are complete and, therefore, how much value has been earned. The example shown in Table 3 gives partial credit for some tasks. It is recommended that partial credit only be allowed for larger tasks and then only in large chunks ($\frac{1}{2}$, $\frac{1}{3}$, or maybe $\frac{1}{4}$).

Table 3 - Earned Value Data, Week ending Oct 29, 1999, Project XXX

<u>Task</u>	<u>Effort (value) (work days)</u>	<u>% Complete</u>	<u>Earned</u>
Set Up	3	100	3
Get Specs	2	50	1
Design Output	10	25	2.5
Plan Tests	3	0	0
Write Code	5	0	0
Unit Test	3	0	0
Integrate	2	0	0
Beta Test	3	0	0
TOTAL	31		6.5 (BCWP)

BCWP or earned value is the total of the "earned" column on the right hand side. Table 3 is recomputed each week, whereas tables 1 and 2 need only be done once. BCWP will increase each week as the project progresses. At any given week, you have the BCWS from table 2 and the BCWP from table 3. ACWP is whatever number of person-days of work have actually been paid for. This is simply the week number multiplied by 5 (total days worked) multiplied

by the number of people, if everyone works full time on just this project. If people share their time between projects or work on non-project activities, their "actual" work hours spent on the project must be determined proportionally.

5.4 Analyzing the Sample Project

Suppose table 3 represents the results at the end of week 3 on the sample project. Suppose the staff did not work 100% on this project, so that only a total of 10 work days have actually been spent on the project. Then:

BCWS = 7 work days (from table 2)
BCWP = 6.5 work days (from table 3)
ACWP = 10 work days (from paragraph above)

Then:

$SV = BCWP - BCWS = -0.50$ (you are behind schedule)
 $SPI = BCWP / BCWS = 0.928$ (you are running at about 93% of the planned schedule)
 $CV = BCWP - ACWP = 6.5 - 10 = -3.50$ (you are 3.5 staff days over budget)
 $CPI = BCWP / ACWP = 0.65$ (you are running over budget by about 35%)

Forecasts:

$IEAC = BAC / CPI = 31 / 0.65 = 47.7$ work days
 $VAC = BAC - IEAC = 31 - 48 = -17$ (17 work days over budget)
 $ISAC = 10 / SPI = 10 / 0.928 = 10.7$ work weeks

In short, your project looks like it will come in about a week late and 35% over budget. What should you do now?

At this point, things look pretty dismal for meeting the cost budget. You need to ask yourself these questions:

- Why is it taking more effort than planned?
 - Did they underestimate the job?
 - Are they losing too much productivity because they are being shared between this project and something else?
 - Were there unforeseen obstacles and, if so, have they been corrected?
 - Is there some other reason?
- Was work performed on other tasks, but not enough to claim partial credit yet on table 3? Maybe things aren't quite as bad as they look

The key point here is that EVA enables you to spot a potential problem early in the project and do something to correct the situation. You can also re-estimate the total project duration and cost at this point, or negotiate changes in the project with your management.

6.0 A Problem with SPI

6.1 The Problem

If a project runs longer than originally scheduled, cost estimating portions of EVA continue to be useful but the schedule estimation portions begin to fail -- the definitions of SV, SPI, and SAC do not work as described above. Instead, they begin to converge toward "on schedule" values and, when the project is complete, they show values of SPI = 1, SV = 0, and SAC = whatever the actual schedule turns out to be. This flaw in earned value analysis results from the fact that the schedule estimates are based on budgets rather than independent evaluations of the schedule.

6.2 Possible Solutions

One option is to use the values of SV, SPI, and SAC only until the originally scheduled completion date and not use them afterwards. This option is simple and it works well in many cases when the main concern is budget overruns rather than schedule overruns, or when the schedule overruns are not very large.

Another option is to re-estimate the schedule and base all future calculations on this new schedule. (In effect, this is what automatically happens with EVA - in the end, the new schedule is whatever the actual schedule happens to be.) Of course with this approach you never have a very good method of predicting how much the schedule overrun will be.

A third option is to develop a new index, DPI or Delivery Performance Index, as an alternative to SPI. DPI is based on the original completion schedules of the individual work tasks. The specific terms and formulas are as follows:

- **Actual Time** - the time actually spent so far, in calendar days.
- **Days Ahead** - how many days ahead of schedule you are (negative if behind schedule). This can be derived from the original schedules of the individual work tasks.
- **DPI** - delivery performance index:
$$\text{DPI} = (\text{Actual Time} + \text{Days Ahead}) / \text{Actual Time}$$

This is harder to do and many accounting systems do not have a mechanism for keeping track of the necessary information. Further definition can be found in (Hudec, 1996) in the references. Working out how to use DPI instead of SPI is a good exercise for the reader.

7.0 References

Bent, James A (1982). Applied Cost and Schedule Control. New York, NY: Marcel Dekker, Inc.

Brandon, Daniel M. (1998, June) "Implementing Earned Value Easily and Effectively." Project Management Journal. Vol 29. Number 2.

Christensen, David S. Comprehensive Bibliography of Earned Value Literature. <http://www.uwf.edu/~dchrste/ev-bib.htm>

Horan, Ron and Don McNichols (1990, September). "Project Management for Large Scale Systems." Business Communications Review 20:19-24.

Hudec, Jim, Gayla Suddarth, et. al, "Experiences in Implementing Quantitative Process Management," Proceedings of the SEI Software Engineering Process Group Conference, May 1996.

Mahler, Fred and Mark Mazina (1982, February). "Earned Value Reporting Earns Its Keep." Cost Engineering 24:13-17.

Nichols, John M (1990). "Project Control." Chapter 15 of Managing Business and Engineering Projects. Englewood Cliffs, NJ: Prentice Hall.

Niemann, William J (1982, May-June). "If the Pharaoh had Only Used an Earned Value System in Building the Pyramids." Program Manager 11:1-5.

Ruskin, Arnold M (1995, September). "Measuring Project Performance: Acceptably Small Inch-pebbles." Engineering Management Journal 7:5-10.

Appendix - An Earned Value Exercise

Objective: The objective of this exercise is to compute earned value metrics and use them to evaluate a project.

Background: Read the *Tutorial on Earned Value Management Systems* that accompanies this exercise. Consider the project described in section 5 of the tutorial. Suppose the table on the next page is an updated version of table 3: (note that ACWP is shown at the bottom)

Task 1: Fill in the values for BCWP, SV, SPI, CV, CPI, IEAC, VAC, SAC and TCPI for each of weeks 1-6 (use the space provided in the shaded portion of the table).

Task 2: On the last page of this exercise, draw a line graph of BCWS, BCWP, and ACWP for each week. I.e., the horizontal axis is week, starting at 0 and going to 12, and the vertical values are in units of work days. There will be three lines; BCWS, BCWP, and ACWP. Extend BCWS to week 10 to show the original plan for completing the 31 units of work.

Task 3: Considering these metrics and graphs, indicate whether the project is ahead of or behind schedule and over or under budget, as of week 6, and indicate what you believe the final cost and schedule will be. Put those answers here:

The project is: _____ schedule and _____ budget

Final Cost is projected to be _____ because

(explain why here)

Final Schedule is projected to be _____ because

(explain why here)

Deliverable: A copy of this exercise in which you have filled in the answers to the various questions that are posed in the tasks above and the table and space below. Put the answers exactly where indicated above.

Table - Earned Value Data, Project XXX							
Task	Effort (value) (work days)	% Complete					
		Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Set Up	3	50	100	100	100	100	100
Get Specs	2	25	50	50	100	100	100
Design Output	10	0	0	25	50	75	100
Plan Tests	3	0	0	0	25	25	50
Write Code	5	0	0	0	0	25	50
Unit Test	3	0	0	0	0	0	0
Integrate	2	0	0	0	0	0	0
Beta Test	3	0	0	0	0	0	0
TOTAL	31						
BCWS		3	5	7	11	15	18
BCWP							
ACWP		3	7	10	15	18	22
SV							
SPI							
CV							
CPI							
BAC		31	31	31	31	31	31
IEAC							
VAC							
SAC							
TCPI							

(use the space below to draw the graph mentioned in task 2)