Practical Performance-Based Earned Value

Paul J. Solomon
PMP

Tuesday, 2 May 2006
Track 5: 2:25 – 3:10 p.m.
Room 251 D-F

Performance-Based Earned Value's® (PBEV℠) foundation, characteristics, and guidelines were described in previous CrossTalk *articles [1] and [2]. This update includes current Department of Defense guidance on systems engineering and practical examples of implementing two of PBEV's four principles. It provides examples of basing earned value on measures of technical progress, on the progress of requirements management activities, and on the entry and exit criteria for technical reviews. This article also includes guidance for using PBEV to monitor a project.*

Performance-Based Earned Value® (PBEV℠) is a set of principles and guidelines that specify effective measures of technical performance for use with earned value management (EVM). Its guidelines are based on standards and models for systems engineering, software engineering, and project management. PBEV also supports Department of Defense (DoD) policy and guides. PBEV ensures that the product requirements baseline, or technical baseline, is incorporated into the performance measurement baseline (PMB). PBEV is an enhancement to the EVM Systems (EVMS) standard [3].

DoD Guides

DoD acquisition policy states that programs implement systems engineering plans (SEP) that include the success criteria for technical reviews [4]. DoD guides that implement the policy include the Defense Acquisition Guidebook (DAG), the Systems Engineering Plan Preparation Guide (SEPPG), the Work Breakdown Structure Handbook (MIL-HDBK-881A [WBS]), and the Integrated Master Plan and Integrated Master Schedule Preparation and Use Guide. Table 1 shows pertinent components of the guides.

The DoD guides refer to EVMS. However, EVMS has significant limitations with regard to the standards and models for systems engineering, software engineering, and project management [2]. Unless these limitations are addressed, there is no assurance that the PMB will include the activities and measures that lead to success. PBEV overcomes these limitations.

For example, the EVMS guidelines specify that earned value (EV) be based on work performed, but only indirectly link EV to meeting the product requirements or the expected quality. In comparison, PBEV bases EV on progress toward meeting the allocated product requirements. PBEV's EV is based on the sum of two measures:

- Progress toward completing the set of enabling work products.
- Progress toward meeting the product requirements.

Table 1: *Department of Defense Systems Engineering Policy and Guides*

DoD Systems Engineering Guides	DAG	SEP	WBS	IMP/ IMS
Develop Systems Engineering Plan (SEP).	4.2.3.2	1.0		
Event-driven timing of technical reviews.	4.5.1	3.4.4	3.2.3.1	2.3, 3.3.2
Success criteria of technical reviews.	4.5.1	3.4.4	3.2.3.1	3.3.2
Assess technical maturity in technical reviews.	4.5.1	3.4.4	3.2.3.1	
Integrate SEP with Integrated Master Plan (IMP).	4.5.1	3.4.5		1.2, 2.3
Integrate SEP with Integrated Master Schedule (IMS).	4.5.1	3.4.5		1.2, 2.3
Integrate SEP with Technical Performance Measurement (TPM).	4.5.1	3.4.4		1.2, 2.3
Integrate SEP with Earned Value Management.	4.5.1	3.4.5		1.2, 2.3
Integrate Work Breakdown Structure (WBS) with requirements specification, statement of work, IMP, IMS, and Earned Value Management System.			2.2.3, 3.2.3.3	3.4.3
Use TPMs to compare actual versus planned technical development and design maturity.	4.5.5	3.4.4		3.3.2
Use TPMs to report degree to which system requirements are met in terms of performance, cost, and schedule.	4.5.5	3.4.4		
Use standards and models to apply systems engineering.	4.2.2 4.2.2.1			
Institute requirements management and traceability.	4.2.3.4	3.4.4		

PBEV Principles and Guidelines

PBEV's foundation, characteristics, principles, and guidelines were previously discussed [2]. Some guidelines that are referenced in this article are included in Table 2.

PBEV Process Flow

A comparison of the PBEV process flow with the traditional EVMS process flow is shown in Figure 1. The PBEV processes and guidelines that supplement EVMS are highlighted. PBEV includes three processes that supplement EVMS that address the product requirements:

- Define the product (also called the technical baseline).
- Integrate product requirements and quality with the plan.
- Measure progress toward meeting product requirements and quality.

A fourth PBEV process addresses risk management:

- Integrate risk management with the plan.

® Performance-Based Earned Value is registered with the U.S. Patent and Trademark Office by Paul Solomon.
℠ PBEV is a service mark of Paul Solomon.

Progress Toward Meeting Requirements

Advice and examples follow for practical implementation of the PBEV guidelines that address the product requirements. The program manager (PM) should select base measures for EV that indicate progress toward development, maturity, implementation, and testing of the product requirements.

Project management processes require progress reporting at periodic intervals, normally monthly. However, progress toward meeting product requirements is not always measurable on a periodic basis. For example, a hardware or software component may require the completion and assembly of many enabling work products such as drawings or coded software modules, before the integrated set of work products may be measured against product quality objectives. Consequently, interim progress measurement is normally against the scheduled completion of enabling work products.

The first two examples apply to PBEV guidelines that address the product requirements (Guidelines 1.1, 2.2, 2.5, 2.6, and 2.7).

Referenced Performance-Based Earned Value Guidelines	
1.1	Establish product requirements and allocate these to product components.
1.2	Maintain bidirectional traceability of product and product component requirements among the project plans, work packages, planning packages, and work products.
2.2	Specify work products and performance-based measures of progress for meeting product requirements as base measurements of earned value. Examples are: • Results of trade-off analysis. • Allocated requirements developed, implemented into design, or tested successfully. • Achieving planned technical performance measures. • Meeting entry and success criteria for technical reviews. • Other quality objectives achieved.
2.4	Identify event-based, success criteria for technical reviews that include development maturity to date and the product's ability to meet product requirements.
2.5	Establish time-phased, planned values for measures of progress towards meeting product requirements, dates or frequency for checking progress, and dates when full conformance will be met.
2.6	Allocate budget in discrete work packages to measures of progress towards meeting product requirements.
2.7	Compare the amount of planned budget and the amount of budget earned for achieving progress towards meeting product requirements.

Table 2: *Referenced Performance-Based Earned Value Guidelines*

Example 1: EV Based on Completing Drawings and Meeting Requirements

Example 1 shows how to base EV on both progress toward completing the set of enabling work products and progress toward meeting the product requirements.

The output of a work package is the design of a component of a subsystem, a set of wire harnesses. There are two requirements that are allocated to the wire harnesses: maximum weight and maximum diameter. The requirements follow:

- Maximum weight: 200 pounds.
- Maximum diameter: 1 inch.

The progress and EV of the work package is measured by both the completion of the enabling work products (drawings) and by meeting the requirements. The schedule for completing the drawings and for meeting the requirements is shown in Table 3 (see page 22).

The budget is allocated as follows: The work package for a component has a budget at completion of 2,000 hours. Each drawing has a budget value of 40 hours.

EV is dependent on the engineering analyses that are performed to determine that the design meets the requirements. EV, also called Budgeted Cost of Work Performed (BCWP), is decreased (negative EV) if a requirement was not met on schedule. EV is restored when the requirement is finally met. The total possible negative EV is 300 hours, as follows:

- Component weight requirement not met: -100.
- Diameter requirement not met: -200.

The schedule status at April month end follows:

- Cumulative drawings completed: 41.
- Diameter requirement met.
- Component weight requirement not met.

Table 4 shows the time-phased Budgeted Cost for Work Scheduled (BCWS), how EV increases for completing the drawings and is reduced if the design fails to meet requirements.

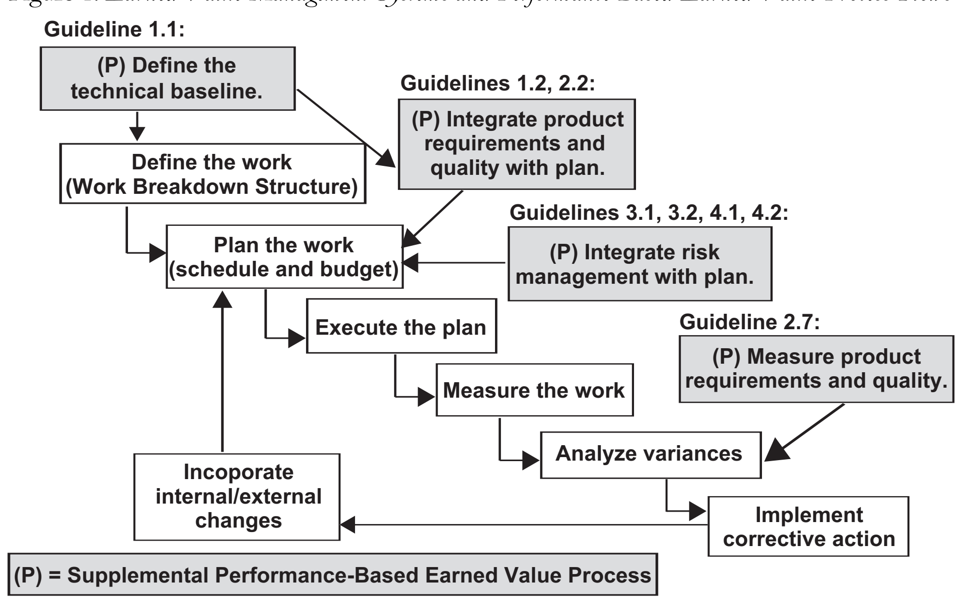
The unfavorable schedule variance analysis should state that the drawings are ahead of schedule (+40) but the design has not met the planned requirements (-100). There will be an unfavorable impact to both the cost and schedule objectives as the drawings are reworked until the design meets the requirements.

A discussion and examples of basing EV on meeting software requirements, including a technique for quantifying deferred functionality, are provided in [1].

Technical Performance Measurement

Technical Performance Measurements (TPMs) are defined and evaluated to assess how well a system is achieving its performance requirements. TPM uses actual or predicted values from engineering measurements, tests, experiments, or prototypes. In Example 1, TPMs are used

Figure 1: *Earned Value Management Systems and Performance-Based Earned Value Process Flows*



Schedule Plan	Jan.	Feb.	Mar.	Apr.	May	Total
Drawings	8	10	12	10	10	50
Requirements Met:						
Weight					1	1
Diameter				1		1

Table 3: *Schedule for Drawings and Requirements*

to determine if the weight and diameter requirements will be met.

Often, during the early stages of drawing development, it may be too early to measure TPM progress. For tasks that are scheduled to complete before the first TPM milestone, EV would be based only on completing drawings per the organization's process quality procedures and standards. Eventually, enough drawings will have been completed to enable the measurement of TPM achievement. If a percentage of the work package budget had been allocated to completing the drawings and another percentage to achieving planned TPM values, then the work package would be held to less than 100 percent complete until the TPM planned values are achieved.

If a TPM planned value is not achieved when scheduled, take negative EV for not meeting that requirement, as was shown in Example 1.

The achievement of significant performance requirements may not be measurable at the component level. If the design of a component is at the work-package level, completion of the design may depend on achieving planned TPMs values or other quality objectives that are only measurable at a higher level of the system architecture or WBS. A technique for constraining EV for a component level work package is to earn part of the work-package budget when the performance objective is met at the higher level of the WBS.

Example 2 is typical during development of a project. A TPM objective is established at the subsystem level. Many, if not all, of the components of the subsystem contribute to technical performance. For a weight TPM, all components play a part. For other TPMs, such as response time, a subset of the components, including both hardware and software components, contributes to the subsystem objective. In Example 2, EV at the component level is based on both the weight of the component (200 pounds) and the weight of the subsystem to which it belongs.

Table 4: *Net Budgeted Cost for Work Performed Based on Component Requirements*

Design (drawings)	Jan.	Feb.	Mar.	Apr.	May	Total
Planned drawings	8	10	12	10	10	50
Budgeted Cost for Work Schedule (BCWS) – current	320	400	480	400	400	2000
BCWS – cumulative	320	720	1200	1600	2000	2000
Actual drawings completed	9	10	10	12		
Budgeted Cost for Work Performed (BCWP) (drawings) – current	360	400	400	480		
BCWP (drawings) – cumulative	360	760	1160	1640		
Negative BCWP (requirements) – cumulative				100		
Net BCWP (drawings and requirements)				1540		
Schedule variance	40	40	-40	-60		

Table 5: *Net Budgeted Cost for Work Performed Based on Component and Subsystem Technical Performance Measurements*

Design (drawings)	Jan.	Feb.	Mar.	Apr.	May	Total
Planned drawings	8	10	12	10	10	50
Budgeted Cost for Work Schedule (BCWS) – current	320	400	480	400	400	2000
BCWS – cumulative	320	720	1200	1600	2000	2000
Actual drawings completed	9	10	10	12		
Budgeted Cost for Work Performed (BCWP) (drawings) – current	360	400	400	480		
BCWP (drawings) – cumulative	360	760	1160	1640		
Negative BCWP (component weight) – cumulative				-100		
Negative BCWP (subsystem weight) – cumulative				-200		
Net BCWP (drawings and requirements with technical performance measures)				1340		
Schedule Variance	40	40	-40	-260		

Example 2: EV When TPM Is At a Higher WBS Level

The assumptions of this example follow:

- The component in Example 1 is one of four components that form a subsystem.
- The subsystem's TPM objective is 4,000 pounds.
- The SEP states that some components may be overweight at completion if there are offsets in other components as long as the total subsystem weight does not exceed 4,000 pounds.

The EV solution for the component that was first shown in Example 1 has changed. In this example, the total possible negative EV is 500 hours, as follows:

- Component weight TPM planned value not met: -100.
- Subsystem weight TPM planned value not met: -200.
- Diameter requirement not met: -200.

In this example, the EV of the work package for a component is dependent on both the measured weight of the component and the weight of the other components within the same subsystem. If both the component and the subsystem weight planned values were not achieved at the April milestone, the net BCWP would be 1,340 hours, as shown in Table 5, Net BCWP Based on Component and Subsystem TPMs. This technique may also incorporate higher levels of the WBS.

Example 3: Progress of Requirements Traceability and Verification

Guideline 1.2 addresses requirements traceability. This guideline supports the SEPPG guidance for the technical management and control section of the SEP. This section of the SEP describes the approach for controlling the overall technical effort of the program, including the technical baseline control and requirements management, traceability, and requirements verification.

Example 3 demonstrates a method for measuring progress of the systems engineering effort to perform requirements management, traceability, and verification. Typical activities include: define the requirement, validate the requirement, determine the verification method, allocate the requirement, document the verification procedure, and verify that the requirement has been met. The requirements traceability matrix (RTM) should be used to record the status of each requirement as it progresses through this cycle. A time-phased schedule for the planned completion of these activities is the basis for the PMB. A measure of the status of the system or subsystem requirements in the RTM should be a base measure of EV.

In Example 3, a system includes five components, 16 total requirements, and six systems engineering activities. The budget allocation is shown in Table 6.

An example of the schedule and the BCWS for the systems engineering effort for one of the components, the enclosure, is shown in Table 7. The time-phased BCWS is determined by allocating the budget for each activity to the month in which it is scheduled.

Software Engineering Budget	Number of Requirements	Software Engineering Budget	Define	Validate	Verify Methods	Allocate	Verify Document	Verify
Budget Percent			15%	15%	15%	20%	15%	20%
Component								
Enclosure	3	240	36	36	36	48	36	48
Transmitter	1	80	12	12	12	16	12	16
Battery	2	160	24	24	24	32	24	32
Control	1	80	12	12	12	16	12	16
Software	9	720	108	108	108	144	108	144
Total	16	1280	192	192	192	256	192	256

Table 6: *Systems Engineering Budget Allocation*

Using PBEV to Monitor a Project

A customer may use PBEV to validate the planning baseline and to monitor the supplier's progress. The customer should utilize the Integrated Baseline Review (IBR) to verify that the SEP includes all required plans, planned values, and process descriptions. The IBR should also be used to verify that the plans, entry criteria, and exit criteria in the SEP are integrated with the master schedule and the work packages. For example, the master schedule should include the criteria for completing technical reviews and milestones for measuring technical performance as well as the TPM planned value to be achieved at that milestone.

Example 4: Exit Criteria

The entrance and exit criteria for event-driven technical reviews should be defined in the SEP. The exit criteria should also be the completion criteria for work packages that map to the reviews. An example of the exit criteria for a system-level detailed (critical) design review, from the systems engineering standard, Institute of Electrical and Electronics Engineers (IEEE) 1220-1998 [5], follows:

- Detailed design satisfies system baseline.
- Design solution meets the following:
  - Allocated functional and performance requirements.
  - Interface requirements.
  - Workload limitations.
  - Constraints.
- Design verification complete for the following:
  - Each requirement constraint is traceable to the physical architecture.
  - Design element solutions satisfy the validated requirements baseline.

PBEV guidelines 2.2 and 2.4 address technical reviews. The customer should apply these guidelines when reviewing the SEP with the supplier. Use the IBR to reach agreement on the entry and exit criteria for all major technical reviews with regard to the technical baselines. The technical baselines are important work products that should be included in the IMS and work packages. The technical reviews described in the DAG with their respective baselines and their IEEE 1220-1998 equivalents are shown in Table 8, DoD Technical Reviews and Baselines.

Following the IBR, the customer is advised to conduct periodic reviews to ensure suppliers are following their plans, procedures, and standards (including those for systems engineering and EVM). The customer should also perform independent assessment of the supplier's progress and verify that the correct base measures are specified and used for EV. The PM should address technical maturity, including TPM achievement and reporting, during technical assessment reviews. Finally, the PM should verify that the supplier has met the exit criteria of event-driven technical reviews.

On a recurring basis, the customer should monitor supplier reports. Review the supplier's EV reports, master schedule, and technical reports to determine if they are consistent; and evaluate supplier metrics (product, schedule, EV) by understanding and questioning the information, including variance analysis. If

Table 7: *Systems Engineering Schedule and Budgeted Cost for Work Scheduled*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Total
Enclosure Schedule								
Defined	3							
Validated		2	1					
Verified Method			1	2				
Allocated					3			
Traced to Verification						3		
Verified							3	
Budgeted Cost for Work Scheduled								
Defined	36							36
Validated		24	12					36
Verified Method			12	24				36
Allocated					48			48
Traced to Verification						36		36
Verified							48	48
Total	36	24	24	24	48	36	48	240

Technical Review	Technical Baseline	DAG	IEEE 1220-1998
System Functional Review	System Functional Baseline	4.3.3.4.3	Validated Requirements Baseline
Preliminary Design Review	System Allocated Baseline	4.3.3.4.4	Verified Physical Architecture
Critical Design Review	System Product Baseline	4.3.3.4.5	Verified Physical Architecture
Production Readiness Review	System Product Baseline	4.3.3.9.3	Verified Physical Architecture

Table 8: *Department of Defense Technical Reviews and Baselines*

the information appears inconsistent or if the variance analysis and corrective action plans are insufficient, conduct reviews to obtain insight into metrics and to better understand the causes and impacts of the variances.

Conclusion

PBEV supplements traditional EVMS with the best practices of systems engineering, software engineering, and project management standards and models. Its principles and guidelines enable true integration of project cost, schedule, and technical performance.◆

References

1. Solomon, Paul J. "Practical Software Measurement, Performance-Based Earned Value." CrossTalk Sept. 2001: 25-29 <www.stsc.hill.af.mil/crosstalk/2001/09/solomon.html>.
2. Solomon, Paul J. "Performance-Based Earned Value." CrossTalk Aug. 2005: 25-26 <www.stsc.hill.af.mil/crosstalk/2005/08/0508solomon.html>.
3. Government Electronics and Information Technology Association. "ANSI Earned Value Management System (EVMD) Standard." ANSI/EIA-748-A-1998 R2002. Arlington, VA <http://electronics.ihs.com/abstracts/geia-standards.jsp>.
4. Wynne, Michael. Policy for Systems Engineering in DoD. Memorandum, 20 Feb. 2004. Acting Undersecretary of Defense, Acquisition, Technology and Logistics.
5. Institute of Electrical and Electronics Engineers. "IEEE Std. 1220-1998 Standard for Application and Management of the Systems Engineering Process." IEEE, Dec. 1998.

Paul J. Solomon will also be presenting a tutorial on integrating systems engineering with earned value management at the SSTC on Monday, 1 May from 8:00 to 11:15 a.m. in room 251 D-F.

About the Author

Paul J. Solomon monitors Earned Value Management Systems (EVMS) for Northrop Grumman Corporation Integrated Systems. He has supported the B-2 Stealth Bomber, Global Hawk, and F-35 Joint Strike Fighter programs. He is an author of the EVMS standard, and received the Department of Defense's David Packard Excellence in Acquisition Award. While a Visiting Scientist at the Software Engineering Institute, he authored "Using CMMI to Improve EVM." His book, "Performance-Based Earned Value," co-authored with Ralph Young, will be published by the Institute of Electrical and Electronics Engineers Computer Society. Solomon is a Project Management Professional. He has a Bachelor of Arts and Master of Business Administration from Dartmouth College.

Northrop Grumman
Integrated Systems
One Hornet WY
TD21/2C
El Segundo, CA 90245
Phone: (310) 335-3308
E-mail: solomonpbev@msn.com