Integrating Systems Engineering with Earned Value Management

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Agenda

- **Federal Policy and Guidance, Customer Expectations, EVM Limitations**
- **Newest Standards, Models, and Best Practices**
- **Project Management with Performance-Based Earned Value® (PBEV℠)**
- **Implementing PBEV into Your Project**
- **IT/Software Progress Measurement Issues**
- **Implementing Better Acquisition Management into Your Project**

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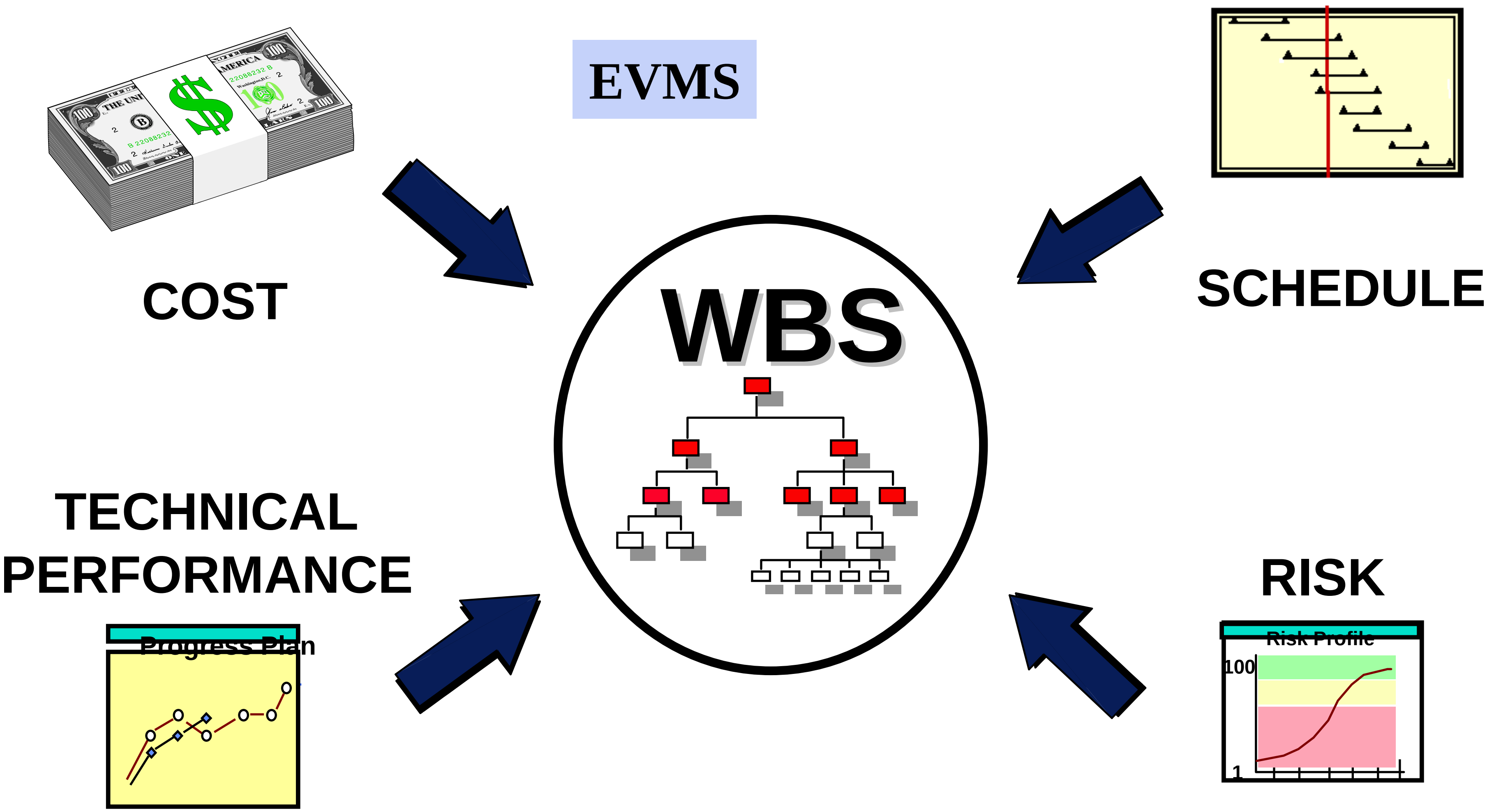
Project Management Shortfalls

- Inadequate early warning
- Schedules, EV overstate true progress
- Remaining work underestimated

Does EVMS Really Integrate?



Value of Earned Value

EVM data will be reliable and accurate only if:

- The right base measures of technical performance are selected

  and

- Progress is objectively assessed.

Federal Policy and Guidance, Customer Expectations, EVM Limitations

Government Pays But Fails to Get Desired Outcomes

GAO Report	Title	Findings and Recommendations
06-66	Defense Acquisitions: DOD Paid Billions in Award and Incentive Fees *Regardless of Acquisition Outcomes*	• Contractors not held accountable for achieving desired outcomes: o Cost goals o Schedule goals o *Desired capabilities* • Programs do not capture early on the requisite knowledge needed to effectively manage program risks
06-391	Defense Acquisitions: Assessments of Major Programs	DOD needs to change its *requirements* and *budgeting* processes to get desired outcomes from the acquisition process

(a) Government Accountability Office

GAO: IT Not Measuring Performance

GAO Report	Title	Findings and Recommendations
06-250	Information Technology: Improve the Accuracy and Reliability of Investment Information	2. If EVM not implemented effectively, decisions based on inaccurate and potentially misleading information 3. Agencies not measuring actual vs. expected performance in meeting IT performance goals.

GAO Best Practices

GAO Report	Title	Findings and Recommendations
04-722 06-215	Information Technology: DOD's Acquisition Policies and Guidance DOD Systems Modernization	Best Practices and Controls: • Ensure that *requirements* are traceable, verifiable, and controlled. • Trace requirements to system design specifications and testing documents. • Continually measure an acquisition's *performance*, cost, and schedule against *approved baselines*.

GAO Best Practices

GAO Report No.	Title	Findings and Recommendations
06-110 06-368	Best Practices: Better Support of Weapons System ,,Needed to Improve Outcomes Defense Acquisitions: Major Weapon Systems Continue to Experience Cost and Schedule Problems	Best Practice Controls: • Complete subsystem and system design reviews • Demonstrate with prototype that design meets requirements • Agreement that drawings are complete and producible

U.S. Federal Policy on SE

DOD Policy & Guidance on SE

Policy for Systems Engineering in DOD Policy 2/20/04

Defense Acquisition Guidebook (DAG) 10/8/04

Systems Engineering Plan Preparation Guide (SEP) 2/10/06

WBS Handbook, Mil-HDBK-881A (WBS) 7/30/05

Integrated Master Plan (IMP) & Integrated Master Schedule Preparation & Use Guide (IMS) 10/21/05

Risk Management Guide for DOD Acquisition (RISK) Aug. 06

DOD Policy on Award Fees (1)

- Link award fees to desired program outcomes
- Tie award fees to
  - Identifiable interim outcomes
  - Discrete events or milestones
    - Timely completion of:
      - Preliminary design review (PDR)
      - Critical design review (CDR)
  - Assessment of interim progress towards PDR, CDR
- Provisions explain how a contractor's progress will be evaluated

Award

Fees

1: OUSD (AT&L) Memo: Award Fee Contracts, 3/29/06

DOD Policy & Guides

Policy or Guide (1 of 3)	Policy	DAG	SEP	WBS	IMS
Develop SEP	P	4.2.3.2	1.0		
Technical reviews:					
• Event-driven timing	P	4.5.1	3.4.4	3.2.3.1	2.3, 3.3.2
• Success criteria	P	4.5.1	3.4.4	3.2.3.1	
• Assess technical maturity		4.5.1	3.4.4	3.2.3.1	
Integrate SEP with:					
• IMP		4.5.1	3.4.5		1.2, 2.3
• IMS		4.5.1	3.4.5		1.2, 2.3
• Technical Performance Measures (TPM)		4.5.1	3.4.4		1.2, 2.3
• EVM			3.4.5		1.2, 2.3

DOD Guides

Guide (2 of 3)	DAG	SEP	WBS	IMS
Integrate WBS with requirements specification, statements of work (SOW), IMP, IMS, and EVMS			2.2.3, 3.2.3.3	3.4.3
TPMs to compare actual vs. plan: • Technical development • Design maturity	4.5.5	3.4.4		3.3.2
TPMs to report degree to which system requirements are met: • Performance • Cost • Schedule	4.5.5	3.4.4		
Standards and models to apply SE	4.2.2 4.2.2.1			
Institute requirements management and traceability	4.2.3.4	3.4.4		

Risk Management Guide for DOD Acquisition

Guides (3 of 3)	IMS	Risk
Contractor: • Incorporate risk mitigation activities into the IMS and budgets • Use IMS and EVM to monitor progress against risk plans	3.5	8.6.6
• Include quantified risk assessments in Estimate at Completion (EAC)		8.6.6

OMB

- Office of Management and Budget (OMB)
- Circular No. A-11, Section 300
  - Planning, Budgeting, Acquisition and Management of Capital Assets
- Section 300-5
  - ***Performance-based*** acquisition management
  - Based on EVMS standard
  - Measure progress towards milestones
    - Cost
    - ***Capability to meet specified requirements***
    - Timeliness
    - ***Quality***

Newest Standards, Models, and Best Practices

Quality

Quality = technical performance:

***Ability* (current or projected)**

of a set of inherent characteristics of a product

Product component or

Process

to *fulfill requirements* of *customers*

CMMI definition

SE Life Cycle Work Products
IEEE 1220

Requirements Analysis

Requirements Baseline

Requirements Validation

Validated Requirements Baseline

Functional Analysis

Functional Architecture

Functional Verification

Verified Functional Architecture

Synthesis

Physical Architecture

Design Verification

Verified Physical Architecture

Requirements trade studies and assessments

Functional trade studies and assessments

Design trade studies and assessments

DOD Technical Baselines

DAG Technical Review	DAG Baseline	DAG	IEEE 1220
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

Performance-Based Progress Measurement

Measure the *allocated requirements* to determine:
- **Development maturity vs. plan**
- **Indicated Quality**

Requirements Progress

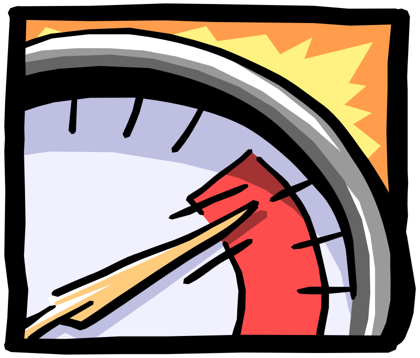
IEEE 1220	EIA-632
6.8.1.5 Performance-based progress measurement 6.8.6 Track product … metrics	4.2.1 Planning process, Req. 10: Progress against requirements
6.8.1.5 d) Assess •*Development maturity* to date •Product's ability to *satisfy requirements* 6.8.6 *Product metrics*…at *pre-established control points* enable: • Overall system *quality* evaluation • Comparison to *planned goals and targets*	Assess *progress* … • Compare system definition *Against requirements* a) Identify *product metrics* and *expected values* ▪ *Quality* of product ▪ Progress towards *satisfying requirements* D) *Compare* results against requirements

Technical Performance Measures (TPM)

IEEE 1220: 6.8.1.5, *Performance-based progress measurement*	EIA-632: Glossary
TPMs are key to progressively assess technical progress	*Predict* future value of *key technical parameters* of the end system based on current assessments
•Establish *dates* for – Checking Progress – Meeting full conformance to requirements	*Planned value* profile is time-phased achievement projected • *Achievement to date* • *Technical milestone where TPM evaluation is reported*

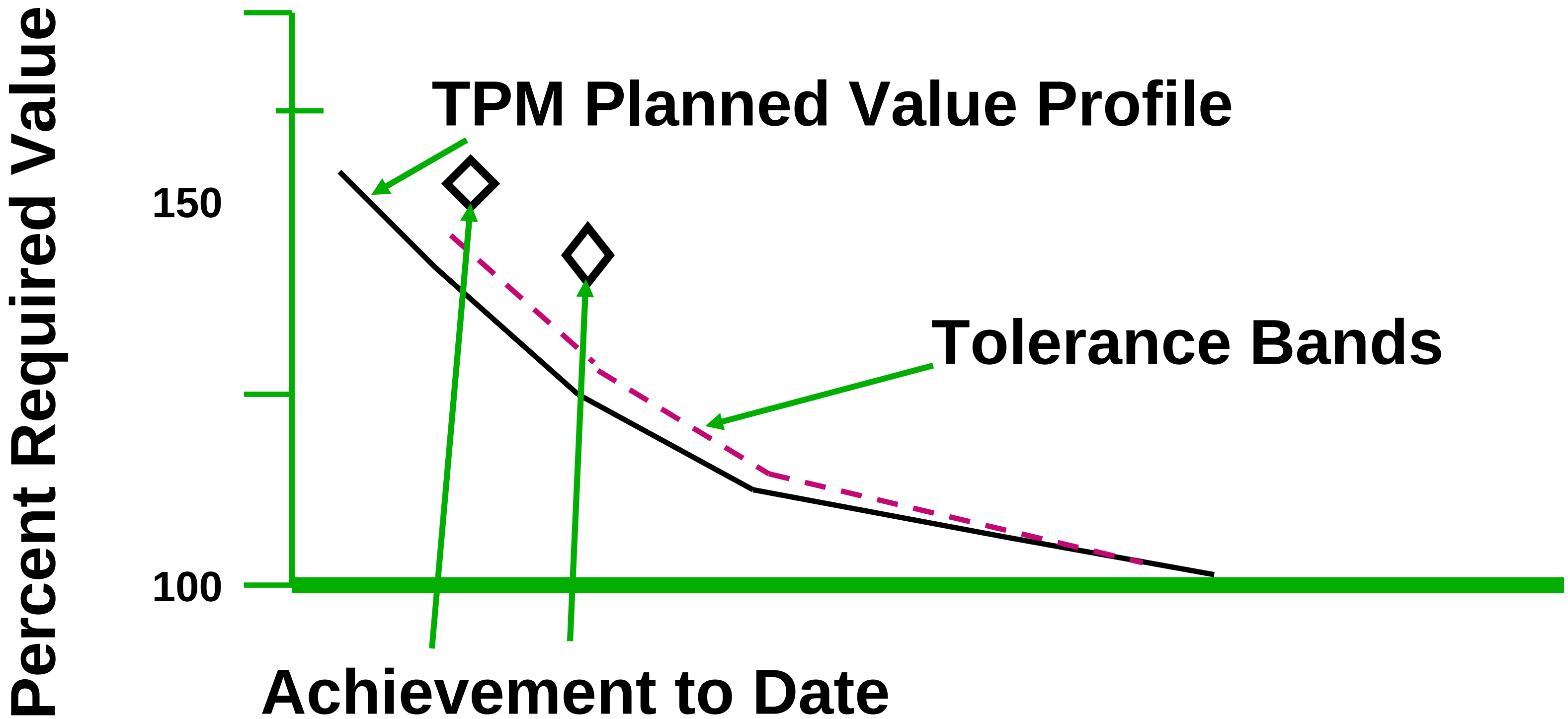
TPM

- **How well a system is achieving performance requirements**
- **Use actual or predicted values from:**
  - **Engineering measurements**
  - **Tests**
  - **Experiments**
  - **Prototypes**
- **Examples:**
  - **Payload**
  - **Response time**
  - **Range**
  - **Power**
  - **Weight**



TPM

Use TPMs as a base measure of EV



INCOSE Warning on TPM

TPM per INCOSE Systems Engineering Handbook
• TPMs express the objective performance requirements.
• *Without* TPM o Project manager could fall into the trap of relying on cost and schedule status alone o Can lead to a product developed on schedule and within cost that does *not meet* all key *requirements.*
• Periodic recording of status of each TPM o Provides continuing verification of degree of anticipated and actual achievement of technical parameters.

Success Criteria and Work Products Per SE Standards

Validated Requirements Baseline

IEEE 1220, (6.2): Success Criteria
• Represents identified customer expectations • Represents constraints – Project – Enterprise – External • Stays within constraints.

Validated Requirements Baseline

<u>IEEE 1220, (6.1, 6.2): Work Products</u>
• Customer expectations • Project, enterprise and external constraints • Operational scenarios • Measures of effectiveness (MOE) • Interfaces • Functional requirements • Measures of performance (MOP) • Modes of operation • Design characteristics • Human factors • Documented trade-offs

Verified Functional Architecture

IEEE 1220, (6.3, 6.4): Work Products

- **Functional context analysis**
  - **Functional behaviors**
  - **Functional interfaces**
  - **Allocated performance requirements**
- **Functional decomposition**
  - **Subfunctions**
  - **Subfunction states and modes**
  - **Data and control flows**
  - **Functional failure modes and effects**

Verified Functional Architecture

IEEE 1220, (6.4): Success Criteria

- **Meets requirements of *validated requirements baseline***
- **System functions decomposed to *lower-level functions* that shall be satisfied by elements of the system design**
  - **Subsystems**
  - **Components**
  - **Parts**
- **Requirements upwardly traceable to the validated requirements baseline**

Success Criteria of Technical Reviews

IEEE 1220, Preliminary design stage
5.2.4.1 Subsystem reviews a. Subsystem definition • Mature – Meet SE milestone criteria a. Component allocations and specifications – Provide a sound subsystem concept c. Subsystem risks assessed and mitigated d. Trade-study data...substantiate that subsystem requirements are achievable

Success Criteria of Technical Reviews

IEEE 1220, 5.2 Preliminary design stage
5.2.4.2 System review • After completion of subsystem reviews • Does total system approach to detailed design *satisfy the system baseline?* • Unacceptable *risks* are *mitigated* • *Issues* for all subsystems, products, and life cycle processes are *resolved* • Accomplishments and plans warrant continued development effort.

Success Criteria of Technical Reviews

IEEE 1220, Detailed design stage (Critical Design Review (CDR))
5.3.4.1 Component reviews a. Detailed component definition…mature..meet • MOE • MOP criteria; c. Risks...mitigated to…support fabrication, assembly, integration, test. d. Trade-study data …substantiate that detailed component requirements are achievable

Success Criteria of Technical Reviews

IEEE. 1220, Detailed design stage
5.3.4.3 System review • After component and subsystem reviews • Does detailed design *satisfy the system baseline?* • Unacceptable *risks* are *mitigated* • *Issues* for all subsystems, products, and life cycle processes are *resolved*

Synthesis (Design)

IEEE 1220, (6.6): Success Criteria
• Design solution meets: – Allocated performance requirements – Functional performance requirements – Interface requirements – Workload limitations – Constraints – Use models and/or prototypes to determine success

Synthesis (Design)

IEEE 1220, (6.6): Success Criteria (continued)
• ***Design solution satisfies*** – ***Functional architecture*** – ***Requirements baseline*** – **(Use models and/or prototypes)** • ***Requirements*** **of the lowest level of the design architecture, including derived requirements, are** ***traceable*** **to the verified functional architecture.**

Design Solution Work Products

IEEE 1220, (6.5, 6.6): Work Products
• Integrated data package to document the selected design elements: – Drawings – Schematics – Software documentation – Manuals – Procedures

Design Solution Work Products

IEEE 1220, (6.5, 6.6): Work Products
• Design solution alternatives • Physical interfaces • Models and prototypes • Failure modes and effects analyses (FMEA) • Requirements traceability and allocation matrices • Trade off analysis results • Finalized design and description of interfaces

EVM Process Improvement through Capability Maturity Model Integration® (CMMI)

Product Requirements

- CMMI, PMBOK Guide: Traceability and consistency

Requirements

Product Require-ments Baseline

Work

- Project Plans
  - Task 1
  - Task 2
  - Task 3
- Activities
- Work Products

Measurement & Analysis

- **CMMI Specific Practice (SP) 1.1:**
  - **Establish *measurement objectives* derived from *information needs* and *objectives***
- **CMMI SP 1.2:**
  - **Specify *quantifiable* measures to address measurement objectives**
    - **Stated in *precise, unambiguous* terms**
    - ***Operational definitions* for the measures**
    - **Specify *how measurement data* will be obtained**
- **EVMS: "by *management assessment*"**

Process and Product QA

- **Product QA**
  - **CMMI:**
    - ***Objectively* evaluate work products against *clearly stated criteria***
    - ***Minimize subjectivity***
  - **EVMS:**
    - **EV is measurement of *quantity* of work**
    - **"*Quality* and *technical* content of work performed are *controlled by other means!*"**

CMMI Typical Work Products

- Requirements Development
  - Product and product-component requirements
  - Interface requirements
  - Required functionality
  - Product component operational concepts, scenarios and environments
  - TPMs

CMMI Typical Work Products

- Technical Solution
  - Operational concepts and scenarios
  - Technical data package
    - Allocated requirements
    - Product-component descriptions
    - Key product characteristics
    - Required physical characteristics and constraints
    - Interface requirements
    - Material requirements
    - Verification criteria to achieve requirements

CMMI Typical Work Products

- Technical Solution
  - Comprehensive product-component interface
    - Interface design specs.
    - Interface control documents
    - Interface specification criteria
  - Implemented design

CMMI Typical Work Products

- Requirements management
  - Requirements traceability matrix (RTM)
- Verification
  - Exit and entry criteria for work products
  - Verification results
- Measurement and analysis
  - Specifications of base and derived measures
- Decision analysis and resolution
  - Results of evaluating alternative solutions (trade-studies)

PMBOK® Guide

PMBOK®, Guide to Project Management Body of Knowledge (ANSI/PMI 99-001-2004, Third Edition)

PMBOK® Guide : Product Scope

PMBOK® Guide (5.5).

- Product scope
  - Features and functions that characterize a
    - Product
    - Service
    - Result
- Project scope
  - Work that needs to be accomplished to deliver a
    - Product, service or result
      with the specified features and functions.

PMBOK Guide®: Quality

- Establish a quality baseline as part of the PMB (8.1.3.5)
  - Integrate technical and quality objectives (10.3.1.5)
- Specify TPMs to measure schedule performance (11.6.2.4)

4. Project Management with Performance-Based Earned Value® (PBEV^{SM})

PBEV

- 4 Principles and 16 Guidelines
- Specify most effective measures of project performance
- Requirements-driven plan
- Consistent with standards and models
- Tailorable and scalable, depending on risk
- Lean

PBEV and Quality

- Link EV with evolving development maturity or *quality*
- *Quantify* quality measures
  - Percent of product requirements met (weighted)
  - Technical performance achieved
- *Measure quality*
  - Of "completed" work products
  - Of work in process

EV without Quality has less management value

PBEV Based on Standards and Models

- ANSI/EIA-632
- IEEE 1220
- CMMI®
- PMBOK® Guide
- INCOSE SE Handbook
- PSM*. Practical Software and Systems Measurement: A Foundation for Objective Project Management*
- Earned Value Management Systems (ANSI/EIA-748-A-1998, reaffirmed August 28, 2002) (EVMS)

PBEV Characteristics

- Integrates SE with EVM
  - Planning:
    - Link performance measurement baseline (PMB) to:
      - Product requirements (technical) baseline
      - SEP
      - SE process work products
    - Identify product metrics for performance-based progress measurement
      - Planned value profile of TPMs
      - Planned development maturity to date
    - Success criteria (reviews and work products)

PBEV Characteristics

- Integrates SE with EVM
  - Measurement
    - Objective measurement of interim progress
    - Progress of requirements through engineering life cycle
    - EV linked with
      - Indicated quality of end product
      - TPM achieved
    - EV used to measure Quality
      - Not just work accomplished

PBEV Characteristics

- Meaningful analysis
  - Correlate analyses of deviations from plan:
    - Technical maturity/quality
    - Schedule
    - Cost

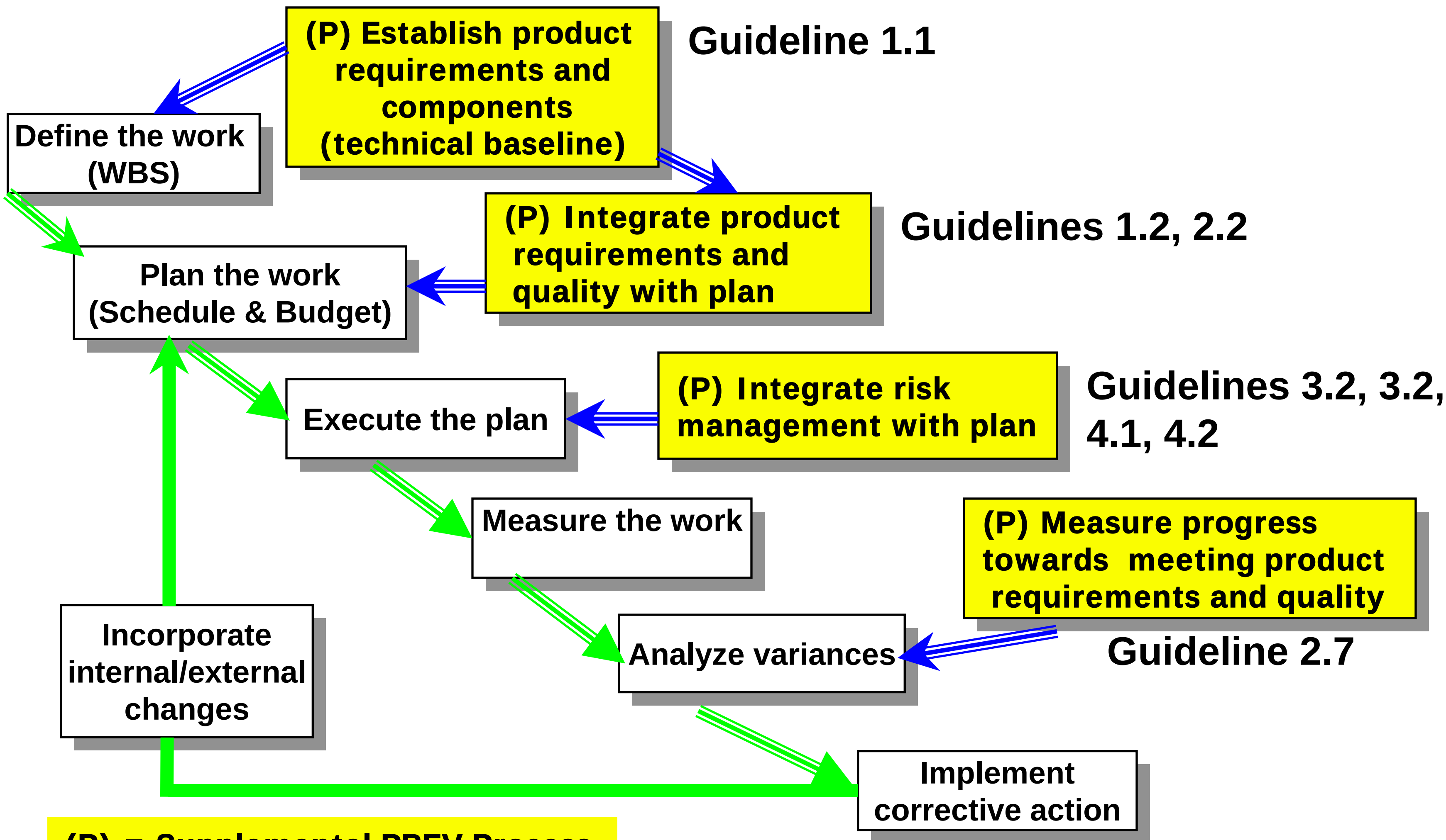
PBEV Characteristics

- Lean
  - Minimizes costs; measurement costs money
  - Fewer work packages with right base measures
    - Product requirements-driven
    - Quality measures
    - Work products
- Applicable to all development models and methods
  - Waterfall, incremental, spiral, V, evolutionary, agile

Principles of PBEV

1. Integrate product requirements and quality into the project plan.
2. Specify performance towards meeting product requirements, including planned quality, as a base measure of earned value.
3. Integrate risk management with EVM.
4. Tailor the application of PBEV according to the risk.

Supplemental PBEV Process Flow



(P) = Supplemental PBEV Process

PBEV Guidelines

1.1 Establish *product requirements* and allocate these to product components.

1.2 Maintain *bidirectional traceability* of *product* and product component *requirements among:*

- **Project plans**
- **Work packages and planning packages**
- **Work products.**

PBEV Guidelines

1.3 Identify *changes* that need to be made to

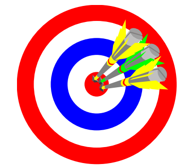
- **Project plans**
- **Work packages**
- **Planning packages**
- **Work products *resulting from changes to the product requirements.***

2.1 *Define the information need and objective*

to measure *progress* towards

satisfying *product requirements.*

PBEV Guidelines



2.2 Specify *work products* and performance-based *measures* of progress for meeting *product requirements* as *base measures of earned value*.

PBEV Guidelines

2.3 Specify *operational definitions* for the base measures of EV,

stated in *precise, unambiguous terms*

Address:

Communication

- **What has been measured**
- **How it was measured**
- **What are the units of measure**
- **What has been included or excluded**

Repeatability: can the measurement be repeated, given the same definition,

to get the same results?

PBEV Guidelines

- **2.4 Identify *event-based success criteria* for technical reviews:**
  - ***Development maturity to date***
  - **Product's ability to meet *product requirements.***

PBEV Guidelines

2.5 Establish:

- **Time-phased, *planned values* for measures of *progress towards meeting product requirements***
- **Dates or frequency for checking progress**
- **Dates when *full conformance will be met.***

2.6 Allocate budget in discrete work packages to measures of progress towards meeting *product requirements*.

PBEV Guidelines

2.7 Compare

- **Amount of planned budget and**
- **Amount of budget earned**

for achieving progress towards meeting *product requirements*

PBEV Guidelines

2.8 Use the level of effort (LOE) method to plan work that is measurable but is

not a measure of progress **towards meeting**

- **Product requirements**
- **Final cost objectives**
- **Final schedule objectives.**

2.9 Perform more effective variance analysis by *segregating discrete effort* from *LOE*.

PBEV Guidelines

3.1 Identify *changes* that need to be made to

- **Project plans**
- **Work packages**
- **Planning packages**
- **Work products**

resulting from *responses to risks.*

3.2 Develop revised EAC

based on *risk quantification*

PBEV Guidelines

4.1 Tailor the application of PBEV
to the elements of the WBS
according to the risk.

4.2 Tailor the application of PBEV
to the phases of the
system development life cycle
according to the risk.

Requirements Development and Management

Manage Requirements

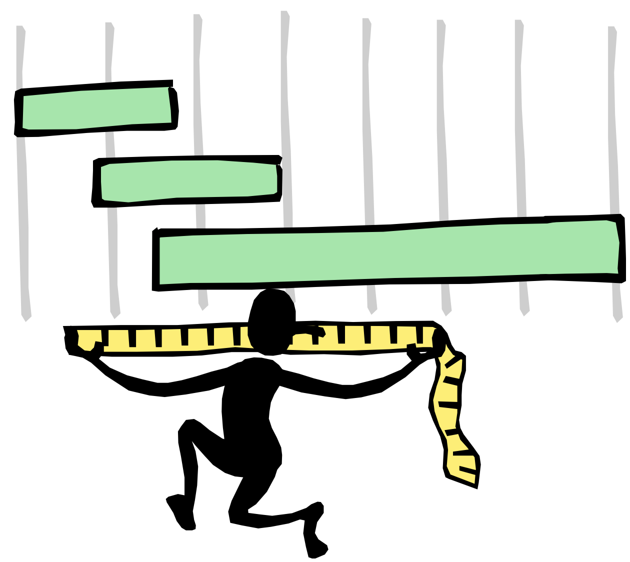
- Second most critical requirements practice
- Example: Use an additional radio band width.
- Changes to plan
  - Trade studies to determine best solution.
  - Budget and schedule changed.
  - All subsequent milestones moved to right
  - Higher cost to customer caused by
    - Level of effort activities extended
    - Skill retention (of people on discrete tasks).

Trade Studies

- Provide objective foundation to select an approach to the solution of an engineering problem.
- Typical trade results:
  - Select user/operational concept
  - Select system architectures
  - Derive requirements
    - Alternative functional approaches to meet requirements
    - Requirements allocations
  - Technical/design solutions
  - Cost analysis results
  - Risk analysis results

Maintaining the Technical Requirements Baseline

- Baseline
  - Specification or product that has been formally reviewed and agreed on.
  - Serves as the basis for further development.
  - Changed only through formal change control procedures.
- Maintaining *product* requirements baseline supports planning and control.



DOD Guidance on SE

Good SE planning:

- **Manage the technical baselines**
- **Technical baselines:**
  - **Are specific SE work products**
  - **Provide product-driven view for SE cost management**
- **Maturity of baselines are entry criteria for event-based technical reviews**
- **EV provides critical insight to technical progress**

Source: Office of the Undersecretary of Defense (Acquisition, Technology & Logistics)/Defense Systems website

Risk Management

Risk vs. Issue

Source: Risk Management Guide for DOD Acquisition:

- **If root cause is described in past tense, it has already occurred. It is an issue.**
- **Incorporate risk mitigation activities into the IMS and EVM**
  - **Monitor progress against risk plans**
- **Include quantified risk impacts in EAC**

EVMS: Not a Risk Management Tool

Significant Variance	Issue?	Risk?
Cost	YES	NO
Schedule	YES	NO

Implementing PBEV into Your Project

PBEV Techniques

- Allocate budget to completion of
  - Enabling work products (drawings, code)
  - Allocated requirements
- Establish milestones with success criteria
  - SE Life Cycle Work Products
  - Number of allocated requirements to be met
  - Technical performance
    - Planned technical maturity
    - Quality

PBEV Techniques

- Measure quality
  - Work products (partial and complete)
  - Technical maturity of evolving product
  - Use analysis, models, simulations, prototypes
- Base EV on
  - Work products (drawings, code) and
  - Quality

PBEV Techniques

- **Use LOE if work is measurable but is *not* a measure of progress towards meeting:**
  - **Product requirements**
  - **Final cost objectives**
  - **Final schedule objectives**

lean

Initial Design Development Measures

- Design (work unit progress):
  - Base EV on
    - # Enabling work products and
      # Requirements met
  - Example:
    - $ # Components designs completed
      and
    - $ # Requirements met traced to components

$ - Recommended PBEV Measure

EX 1: EV Based on Drawings and Requirements

- **SOW: Design a subsystem with 2 TPM requirements:**
  - **Maximum (Max.) weight: 200 lb.**
  - **Max. diameter: 1 inch**
- **Enabling work products: 50 drawings**
- **BAC: 2000 hours**
  - **Drawings: 40 hours/drawing @ 50 — 2000**
  - **Requirements *not* met on schedule:**
    - **Potential negative EV**
      - **Weight: -100**
      - **Diameter -200**

EX 1: Schedule Plan and Status

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

Status at April 30

- **Drawings completed: 41**
- **Weight requirement *not* met**
- **Diameter requirement met**

EX 1: Earned Value

Design (drawings)	Jan.	Feb.	Mar.	Apr.	May	Total
Planned drawings cur	8	10	12	10	10	50
Planned drawings cum	8	18	30	40	50	
BCWS cur	320	400	480	400	400	2000
BCWS cum	320	720	1200	1600	2000	2000
Actual drawings completed cur	9	10	10	12	8	
Actual drawings completed cum	9	19	29	41	49	
EV (drawings) cum	360	760	1160	1640	1960	
Negative EV Reqs cum					-100	
Net EV cum	360	760	1160	1640	*-1860*	

SV = - 140

EX 1: Variance Analysis

Variance analysis (drawings and requirements):

• 1 drawing behind schedule	- 40
• Diameter requirement met	- 0
• Weight requirement *not* met:	- 100
Schedule variance	- 140

TPM at Higher WBS Level

- Design of a component at the work package level
- Completion of the comp. design depends on
  - Achieving allocated TPMs values at
    1. Component level *and*
    2. Subsystem level
- EV is dependent on planned TPM values achieved at *both* levels

TPM at Higher WBS Level

- For a weight TPM, all components play a part
- For other TPMs, such as response time
  - Subsets of the components combine to meet subsystem performance objectives
    - Hardware components
    - Software components

TPM at Higher Level

- **Assumptions:**
  - Component in Example 3 is one of four components that form a subsystem
  - Subsystem's TPM objective is 4000 lb.
  - SEP states:

    Some components may be overweight at completion if there are offsets in other components (Comp)

    as long as the total subsystem (Sub) weight does not exceed 4000 lb.

EX 2: TPM at Higher WBS Level

Component, Work Pkg.	TPM Planned Value	Planned Completion	Component EV Penalty	Subsystem EV Penalty
1	200	April	-100	-50
2	1000	April	-500	-250
3	2000	May	-1000	-500
4	800	May	-400	-200
Subsystem total	4000		-2000	-1000

TPM at Higher WBS Level

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Planned drawings cur	8	10	12	10	10	50
Planned drawings cum	8	18	30	40	50	
BCWS cur	320	400	480	400	400	2000
BCWS cum	320	720	1200	1600	2000	2000
Actual drawings completed cur	9	10	10	12	8	
Actual drawings completed cum	9	19	29	41	49	
EV (drawings) cum	360	760	1160	1640	1960	
Negative EV Reqs cum					- 1500	
Net EV cum	360	760	1160	1640	*460*	

Ex. 3: Rework in Same WP

Design (drawings)	Jan.	Feb.	Mar.	Apr.	May	Total
Planned drawings –cur.	8	10	12	10	10	50
Planned drawings –cum.	8	18	30	40	50	50
BCWS – cum.	320	720	1200	1600	2000	2000
Drawings completed	9	10	10	4		
Drawings returned				- 5		
Net drawings – cur.	9	10	10	-1		
Net drawings – cum.	9	19	29	28		
Net EV – cur.	360	400	400	-40		
EV – cum.	360	760	1160	1120		
SV – cum.	0	40	-40	-480		

Drawings Returned for Rework Result in Negative EV

Ex 4: Rework in Separate WP

WP 1: Initial development of drawings	Jan.	Feb.	Mar.	Apr.	May	Total
Planned number of drawings	8	10	12	10	10	50
BCWS	288	360	432	360	360	1800

Planned rework in WP 2

WP 2: Rework of Drawings	Jan.	Feb.	Mar.	Apr.	May	Total
BCWS			60	70	70	200

Ex 4: Rework in Separate WP

WP 2: Rework of Drawings	Jan.	Feb.	Mar. MS 1	Apr. MS 2	May MS 3	Total
BCWS			60	70	70	200

Rework Milestones:

- **Milestone 3: 100 % of drawings meet requirements**
- **Milestone 2: 90 % of drawings meet requirements**
- **Milestone 1: 80 % of drawings meet requirements**

EX 5: Trade Study

- Outcome is usually a recommendation that is needed to make a decision.
- Decision constrains and guides further progress.
- Work product: documented trade study results.
- Engineering processes should include a process and structured approach for performing trade studies.
  - Process should include both interim and final work products that can be:
    - Planned, scheduled, and measured.

Trade Study Outline

1. Purpose of Study:
   – Resolve an issue
   – Perform decision analysis
   – Perform analysis of alternatives
2. Scope of study
   – State level of detail of study
   – State assumptions
   – Identify influencing requirements and constraints.

Trade Study Outline

3. Trade study description

   Describe trade studies to be performed to make tradeoffs among:

   – Concepts
   – User requirements
   – System architectures
   – Design
   – Program schedule
   – Functional performance requirements
   – Life-cycle costs

Trade Study Outline

4. Analytical approach
   - Identify candidate solutions
   - Measure performance
   - Develop models and measures of merit
   - Develop values for viable candidates
   - Selection criteria: (normally risk, performance, cost)

Trade Study Outline

5. Scoring
   – Determine measures of results to be compared to criteria
   – Assign weights to measures of results reflecting their relative importance
   – Perform sensitivity analysis
6. *Evaluate alternatives*
7. Documentation of trade results

Trade Study Schedule

Trade Study Base Measures: Evaluate Alternatives	Time Period
Initial evaluation of each of 5 candidates has three milestones: • Start test set up • Tests executed to completion • Analyze and document	 1 2 3
Down select from 5 candidates to 2 candidates	3
Document recommendation	4

Trade Study EV

- Evaluation activity planning assumptions
- Total Budget: 1000 hours
  - Test and evaluate 5 candidates: 500
    - 100 per candidate
    - Take EV even if candidate discarded before test complete
  - Down select to 2 candidates: 200
  - Document final recommendation: 300
- Period of Performance: 4 months

EX 6: Requirements Management

- Discretely measure requirements management
- Use RTM to control plan
- Requirements management (RM) tasks
  - Defined
  - Validated
  - Determined verification method
  - Approved
  - Allocated
  - Traced to verification document (test procedure)
  - Tested
  - Verified
- Key indicator of project performance

Requirements Allocation Measures

$ – # requirements traced to software or hardware components

Note: Budget per Work Unit does not have to be equally distributed

$ - Recommended PBEV Measure

Budget Allocation

SE Budget	No. Reqs.	SE Budget	Define	Valid.	Verif. Meth.	Alloc.	Verif. Doc.	Verify	Total
Budget %			15%	15%	15%	20%	15%	20%	100%
<u>Component</u>									
Enclosure	3	240	36	36	36	48	36	48	240
Transmitter	1	80	12	12	12	16	12	16	80
Battery	2	160	24	24	24	32	24	32	160
Control	1	80	12	12	12	16	12	16	80
Software	9	720	108	108	108	144	108	144	720
Total	16	1280	192	192	192	256	192	256	1280

Microsoft Excel Worksheet

Time-Phased Budget

		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Total
Enclosure									
Schedule									
Defined		3							
Validated			2	1					
Verif. Method				1	2				
Allocated						3			
Traced to Verif.							3		
Verified								3	
BCWS current	Budget/Activity								
Defined	12	36							36
Validated	12		24	12					36
Verif. Method	12			12	24				36
Allocated	16					48			48
Traced to Verif.	12						36		36
Verified	16							48	48
Total		36	24	24	24	48	36	48	240
BCWS cumulative		36	60	84	108	156	192	240	

Earned Value

		Jan	Feb	Mar	Apr	May
Enclosure						
Completed	Budget/Activity					
Defined	12		3			
Validated	12				1	1
Verif. Method	12				1	
EV cumulative		0	36	36	60	72
BCWS cumulative		36	60	84	108	156
Schedule Variance		-36	-24	-48	-48	-84

EX 7: PBEV Variance Analysis

- Negative EV causes sudden schedule and cost variances
- Example: New schedule variance when TPM planned value not achieved.
  - Requirements for control console:
    - Maximum surrounding temperature (Max.) < 100 degrees F. for more than 30 seconds
    - Max. never > 120 degrees
  - Prior status
    - Designs on schedule
      - Control console
      - Nearby equipment
      - Cooling methods
    - Thermal analyses on schedule
    - Meets TPM planned values at lower WBS levels

PBEV Variance Analysis

- Known performance issue
  - TPM planned value not achieved
  - Max. > 120 degrees
- Negative EV results in significant schedule variance
- How to describe in variance analysis?

PBEV Variance Analysis

- Cause:
  - Insufficient space between surrounding components
  - Insufficient airflow to cool the equipment
  - Root cause:
    - Requirements did not limit dimensions of cables and connectors
- Impact:
  - 4 week delay for redesign
  - Cost increase of & 50 K for redesign, retest
- Corrective Action Plan:
  - Rework requirements, design, test
  - Improve requirements development and validation process

PBEV EAC Tip

- If significant technical issues exist,
  only detailed planning can provide reliable EAC
- If significant risks exist (high probability and cost impact), include cost impact in EAC

IT/Software Progress Measurement Issues

Initial Development: Incremental Capability

- **Document baseline content of incremental builds**
  - **# functional requirements**
  - **# components**
- **Baseline the build milestones and completion criteria**
- **Baseline the build work packages and EV metrics**
- **Take EV based on functionality achieved**
  - **Show completed milestones & take full earned value**

    Only if **all completion criteria and planned functionality attained**

Internal Replanning of Deferred Functionality

- **If build is released short of planned functionality:**
  - **Take partial EV and leave work package open**
    or
  - **Take partial EV and close work package**
    - **Transfer deferred scope and budget to first month of work package for next incremental build**
      - **EV mirrors technical performance**
      - **Schedule variance retained**
    - **Disclose shortfall and slips on higher schedules**

EX 8: Deferred Functionality

- **SOW: Software Requirements in 2 Builds:**

Build	Allocated Req.	Budget/Req.	BAC
A	100	5	500
B	60	5	300

SW Build Plan

	Jan	Feb	Mar	Apr	May	Jun	Jul	Total
Build A								
Planned Reqs. met	25	25	25	25				100
Budget/Req.: 5 hours								
BCWS current (cur)	125	125	125	125				500
BCWS cumulative (cum)	125	250	375	500				500
Build B								
Planned Reqs. Met					20	20	20	60
BCWS cur					100	100	100	300

Deferred Functionality Status

	Jan	Feb	Mar	Apr	Total
Build A					
Planned Reqs. Met cur	25	25	25	25	100
Actual Reqs. Met cur	20	20	25	25	90
BCWS cur	125	125	125	125	500
EV cur	100	100	125	125	450
BCWS cum	125	250	375	500	
EV cum	100	200	325	450	
Schedule variance (SV):					
Reqs. Met	-5	-10	-10	-10	
SV	-25	-50	-50	-50	

Deferred Functionality Replan

	Apr	May	Jun	Jul	Total
Close Build A work package					
SV:					
Reqs. Not Met	-10				-10
BCWS remaining	-50				-50
Build B					
Before Replan:					
Planned Reqs. Met		20	20	20	60
BCWS cur		100	100	100	300
Plus transfer:					
Reqs.		+10			
BCWS		+50			
After replan:					
Planned Reqs. Met		30	20	20	70
BCWS cur		150	100	100	350

Deferred Functionality Status

	May	Jun	Jul	Total
Build B After Replan:				
Planned Reqs. Met	30	20	20	70
BCWS cur	150	100	100	350
Actual Reqs. Met cur	20			20
EV cur	100			100
Schedule variance cum:				
Reqs. Met	-10			
SV	-50			

Software Quality Measures

- Software quality measures are TPMs
  – Defect density
  – Number of problem reports
- Failure to achieve planned quality indicates
  - More rework during development
  - More problems after product delivery

Ex 9: Quality as a Limiter of EV

- TPM: Number or density of defects
- If defect plan/quality goals are not attained:

  Use Hammervold Algorithm:
  - Assumes that more defects than planned will be found in future
  - Assumes that some verified requirements will be negated by future defects
  - Limits EV to 80% of BAC even if % requirements met > 80%

Implementing Better Acquisition Management into Your Project

Acquisition Management

Ensure Contractors Integrate SE with EVM

- **Requirements, incentives, insight:**
  - Solicitation/Request for Proposal (RFP)
  - Integrated Master Plan (IMP)
  - Integrated Baseline Review (IBR)
  - Integrated Master Schedule (IMS)
  - EVMS compliance assessments
  - Independent technical assessments
  - Monitor consistency and validity of reports
  - Independent EAC and risk assessments
  - Award fee criteria

IMP

- Event-based technical reviews
  - Appropriate entry and exit criteria
- Show build up from unit design and test to subsystem to system integration
- Software development and integration approach reflected in significant accomplishments and criteria

IBR

- Review implementation of SE:
  - Entry and success criteria for IMP events
  - Requirements management and traceability
  - Control points for product metrics and TPMs
  - Milestones with technical maturity success criteria
    - TPM planned values
    - Meeting requirements
    - Percent of designs complete
  - SE life cycle work products in IMS

IBR

- Confirm integration of
  - Technical baseline
  - WBS
  - IMP/IMS
  - EVM
  - Risk management

IMP > IMS Flowdown

- **Meeting all the IMP criteria indicates completion of the significant accomplishment.**
- **The IMS should decompose IMP criteria into tasks necessary to meet the criteria.**

IMS Checklist

- Review completion criteria for significant accomplishments
  - Objective and measurable
- Review each significant accomplishment
  - Do events occur at the system level and across multiple Integrated Product Teams (IPT)?
  - Does each criterion relate to a specific IPT?

IMS Checklist

- Subcontracted efforts
  - Appropriate visibility?
    - Requirements flowdown
    - Design reviews prior to system level reviews
- IMS traceable to EVMS work and planning packages
  - Timing
  - Completion criteria
  - WBS numbers

Independent Technical Assessments

- Verify technical maturity
  - Product and Quality metrics
    - TPM achievement
    - Requirements met

Monitor Consistency and Validity of Reports

- Compare performance reports for consistency:
  - Program status
    - Technical
    - Schedule
    - EV
  - Variance analyses
    - Root causes
    - Corrective action plans
    - Impacts on cost and schedule

Independent Assessments of EAC and Risks

- Perform EAC and quantified risk assessments
  - At total contract level
  - At lower WBS levels
- Compare your assessment with supplier’s
- Resolve significant differences
- Validate supplier’s corrective action plans
  - Performance efficiency
  - Schedule recovery

Award Fee Criteria for Successful IBR

- Agree on:
  - Entry and exit criteria for event-based technical reviews
  - Objective completion criteria for each significant accomplishment needed to support reviews.
- Subcontracted efforts on IMS have sufficient:
  - Milestones
  - Accomplishments
  - Completion criteria
- Completions of subcontractor design reviews occur prior to system level design reviews.

Award Fee Criteria for Successful IBR

- **Management process provides effective:**
  - **Integrated technical/schedule/cost planning**
  - **Baseline control**
- **Valid critical path**
- **Technical baselines are included in the IMS**
- **TPM milestones are in IMS with planned values**
- **IMS milestones and completion criteria traceable to EVMS work and planning packages**

Award Fee Criteria for Successful IBR

- Process, bidirectional traceability among:
  - Requirements
  - Work products
  - Project plans (IMS, work and planning packages)
- IMS includes activities identified in risk mitigation
- PMB is sufficient to successfully execute the project

Award Fee Criteria for Successful Technical Reviews

- All exit criteria for event-driven technical reviews met on schedule
  - Development maturity is on schedule
  - Issues resolved
    - All subsystems
    - Products
    - Life cycle processes
- Unacceptable risks are mitigated

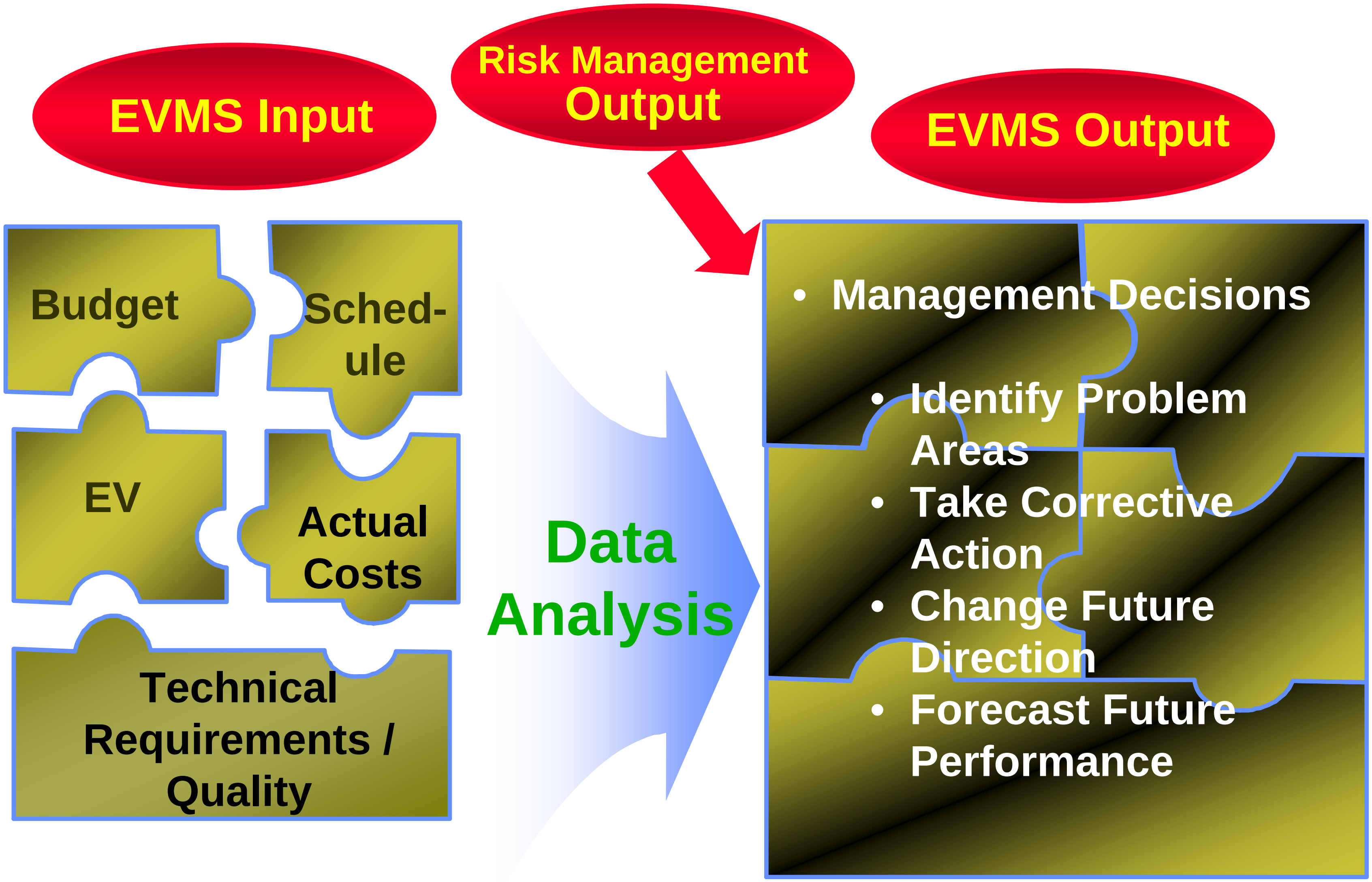
Award Fee Criteria for Successful Technical Reviews

- System design is capable of meeting requirements
- Cost performance objectives have been met
- Bidirectional traceability is maintained among the requirements and the project plans, work products, and work packages.
- Accomplishments and plans satisfy criteria for continuation of the technical effort

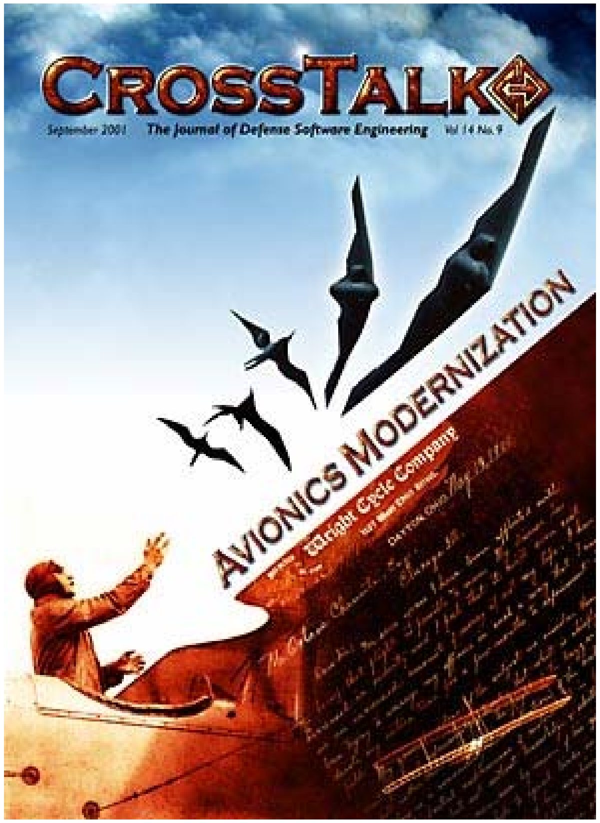
Summary

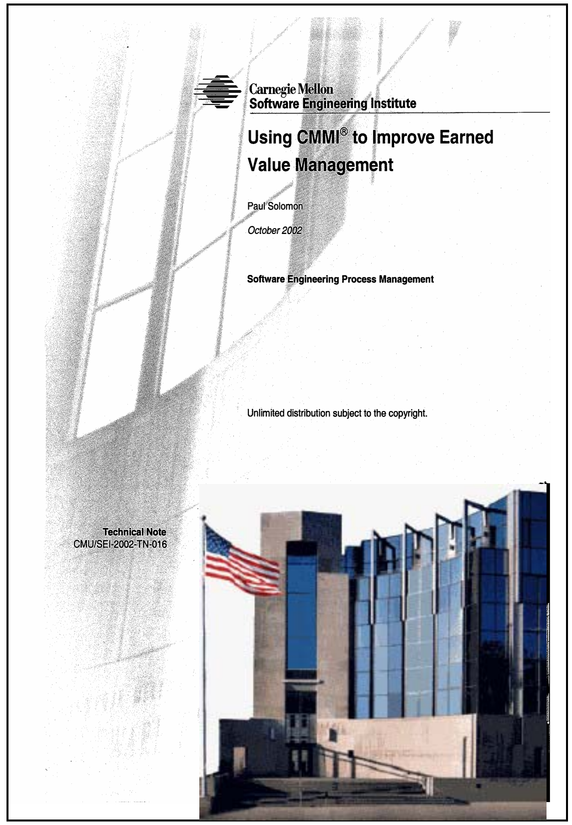
- Integrate
  - Systems engineering with PBEV
    - Product requirements
    - Manage the technical baseline
    - Technical performance measures
    - SE life cycle work products
  - Technical>schedule>cost performance
- Lean process
  - Less work packages with right base measures
- Agile

Benefits of Using PBEV



Process Improvement

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Paul Solomon

October 2002

Software Engineering Process Management

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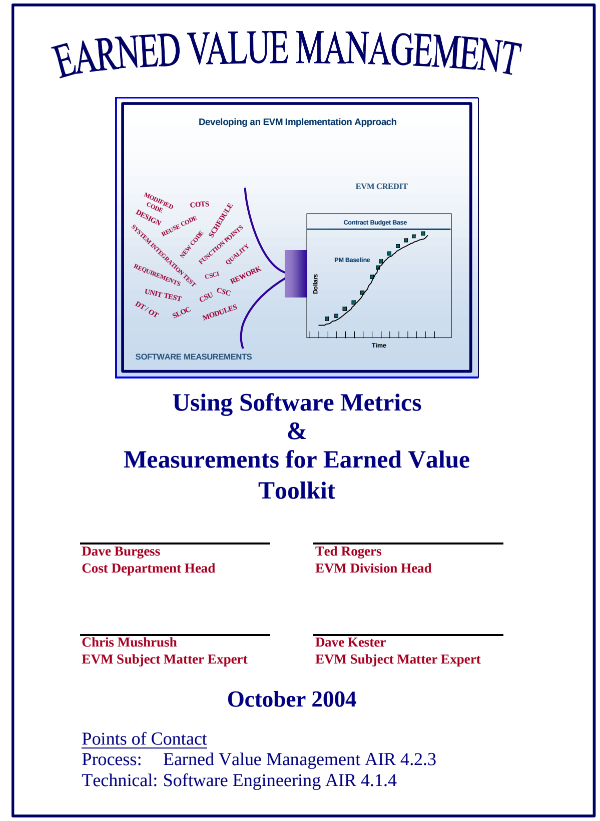

EARNED VALUE MANAGEMENT

Developing an EVM Implementation Approach

Using Software Metrics
&
Measurements for Earned Value
Toolkit

Dave Burgess
Cost Department Head

Ted Rogers
EVM Division Head

Chris Mushrush
EVM Subject Matter Expert

Dave Kester
EVM Subject Matter Expert

October 2004

Points of Contact
Process: Earned Value Management AIR 4.2.3
Technical: Software Engineering AIR 4.1.4

Sept. 2001
Aug. 2005
May 2006

SEI / CMMI

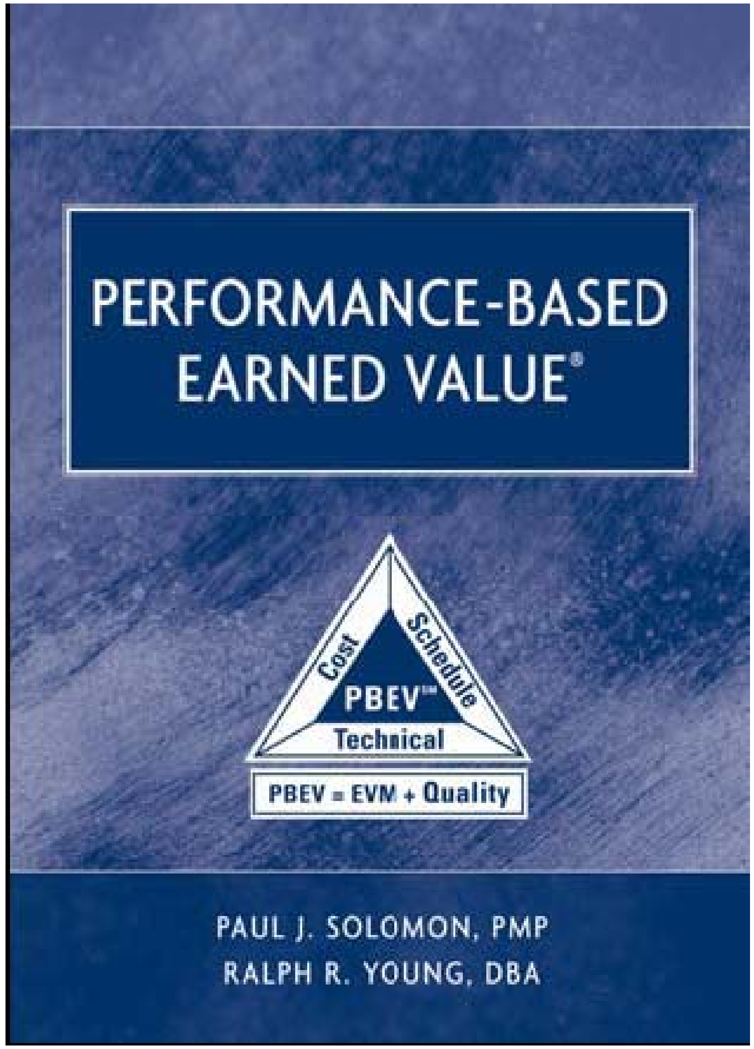
NAVAIR

Process Improvement

But wait.

There's more!

- **Examples**
- **Templates**
- **Tips**
- **Standards**
- **FAR**



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References

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- American National Standards Institute (ANSI)/Electronics Industries Alliance (EIA). ANSI/EIA 632, *Processes for Engineering a System*, EIA, Arlington, VA, 1998.
- CMMI, *Capability Maturity Model Integration-Systems Engineering/Software Engineering/Integrated Product and Process Development, Version 1.1*, 2002.
- INCOSE 2006. International Council on Systems Engineering (INCOSE). *INCOSE Systems Engineering Handbook, version 3.* June 2006. page 7.11
- Institute of Electrical and Electronics Engineers (IEEE). IEEE Std 1220™-2005*, IEEE Standard for Application and Management of the Systems Engineering Process. New York, 2005.*
- Naval Air Systems Command (NAVAIR*). "Using Software Metrics & Measurements for Earned Value Toolkit.*" Department of the Navy (October 2004).

References

- PSM. *Practical Software and Systems Measurement: A Foundation for Objective Project Management*, Version 4.0b, October 2000 (www.psmsc.com).
- Solomon, Paul . "Practical Software Measurement, PBEV", *CrossTalk* (September 2001) www.stsc.hill.af.mil/crosstalk/2001/09/index.html.
- Solomon, Paul. "Going From PBEV to the CMMI", *CrossTalk* (September 2002) www.stsc.hill.af.mil/crosstalk/2002/09/index.html.
- Solomon, Paul , "Using CMMI to Improve Earned Value Management" (CMU/SEI-2002-TN-016) (October 2002). www.sei.cmu.edu/publications/documents/02.reports/02tn016.html
- Solomon, Paul , "Integrating Systems Engineering with Earned Value Management", *Defense Acquisition, Technology and Logistics (AT&L) Magazine* (May 2004). www.dau.mil/pubs/dam/05_06_2004/may-june04.pdf.
- USAF Space & Missile Systems Center, "Systems Engineering Primer and Handbook" (January 2004)
- Young, Ralph R. *Effective Requirements Practices* (Addison-Wesley, 2001).
- Solomon, Paul. "Performance-Based Earned Value", *CrossTalk* (August 2005) www.stsc.hill.af.mil/crosstalk/2005/08/index.html.
- Solomon, Paul. "Practical, Performance-Based Earned Value", *CrossTalk* (May 2006)

Acronyms

- BCWP: Budgeted Cost for Work Performed
- BCWS: Budgeted Cost for Work Scheduled
- EV: Earned Value = BCWP
- EVMS: Earned Value Management System
- IBR: Integrated Baseline Review
- IMP: Integrated Master Plan
- IMS: Integrated Master Schedule
- PBEV: Performance-Based Earned Value
- SEP: Systems Engineering Plan
- SOW: Statement of Work
- TPM: Technical Performance Measure
- WBS: Work Breakdown Structure