Tutorial: Integrate Systems Engineering with Earned Value Management

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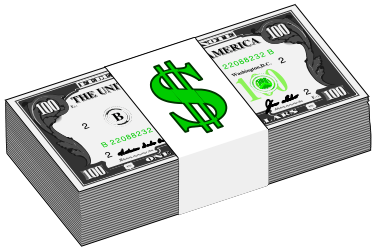
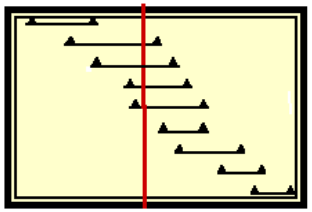
Agenda

- Link EV to Technical Performance/Quality
- Government Needs and Acquisition Reform
- Guidance in Standards, Models and DoD Guides
- Practical Application
  - Technical Performance Measures
  - Rework
  - Trade studies
  - Requirements Management and Traceability
  - IT/ Software Development Measures and Issues
  - Agile methods
- Acquisition Management
- Framework for Process Improvement

Does EVMS Really Integrate?



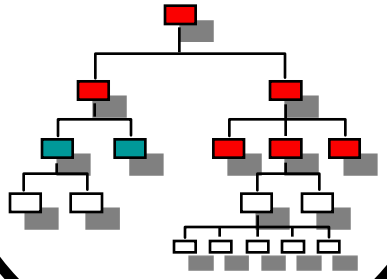
EVMS



COST

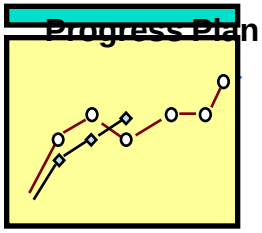
SCHEDULE

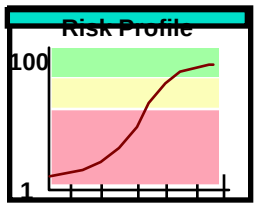
WBS



TECHNICAL PERFORMANCE

RISK





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" (a)**

(a) "Integrating Systems Engineering With Earned Value Management" in *Defense AT&L Magazine*, May 2004

Government Needs
and
Acquisition Reform

Office of Management and Budget

- **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***

Federal Acquisition Regulation (FAR) 2.101.b; EVMS

EVMS Definition:

- **Program management tool that effectively integrates project scope of work with:**
  - **Cost**
  - **Schedule**
  - ***Performance* elements**
- **Qualities and operating characteristics of an EVMS are described in ANSI-748 (EVMS)**

But ANSI-748 has *Performance/Quality gap*

Weapons System Acquisition Reform Act of 2009 (WSARA)

Directs DOD to provide recommendations to improve EVM and it implementation:

- ***Discuss merits of possible alternatives***
- ***Submit plan for possible improvements***

Sen. Collins, conference report:

- **GAO observed that contractor EVM reporting**
  - **Lacks consistency**
  - **Leads to inaccurate data and faulty application of the EVM metric.**
- **"In other words, *garbage in, garbage out*."**
- **"With improved EVM data quality,**
  - **Both the government and the contractor will be able to improve program oversight,**

  leading to better acquisition outcomes."

DoD EVM Report Required by WSARA

Report: *DoD Earned Value Management: Performance, Oversight, and Governance, 2010*

"Utility of EVM has declined to a level where it does not serve its intended purpose."

Findings and Recommendations:

- **Inaccurate EVM status data provided by vendors**
- **Change in...culture is necessary**
- **Use Technical Performance Measures (TPM)**
- **Integrate Systems Engineering with EVM**

DoD Report: Accuracy (1 of 2)

Accuracy of EVM status data provided by vendors

- **Schedules often cannot show downstream impacts of problems or cannot determine the critical path driving contract completion**
- **When assessing cost and schedule variances, contractors cannot effectively identify the root cause, impact, and appropriate corrective actions**
- **Contractors do not have a process for developing reliable EAC**
- **Contractor change control processes do not maintain the integrity of the PMB**

DoD Report: Accuracy (2 of 2)

- Many instances of inappropriate changes
  - Arbitrarily changing past variances
  - Moving budgets to mask overruns
  - Making changes that were not properly authorized
- End result
  - Many Defense contractors cannot accurately predict outcomes that affect program costs or deliveries
  - Data quality problems hinder the government's ability to meet program objectives by delaying or masking insight into developing problems

DoD Report: Culture

Change in...culture is necessary

- **Program Managers should identify and quantify the impacts of schedule slips and cost overruns**
- **Contractors may circumvent proper EVM practices to keep EVM metrics favorable and problems hidden**
- **Engineering community should establish TPMs that enable objective confirmation that tasks are complete**

DoD Report : SE

Integrate SE with EVM

- **EV process is reliable and accurate only if**
  - **Augmented with a rigorous SE process**
  - **SE products are costed and included in EVM tracking**

DoD Report : TPM (1 of 2)

Use TPMs

- **EV process is reliable and accurate only if**
  - **TPMs are identified and associated with completion of appropriate work packages**
  - **Quality of work must be verified**
  - **Criteria must be defined clearly and unambiguously**

DoD Report : TPM (2 of 2)

Use TPMs

- **If good TPMs are not used:**
  - **Programs could report 100 percent of earned value..even though behind schedule**
    - **Validating requirements**
    - **Completing the preliminary design**
    - **Meeting weight targets**
    - **Delivering software releases that meet the requirements**
- **PM ensure that the EVM process measures the quality and technical maturity of technical work products instead of just the quantity of work performed**

National Defense Authorization Act for FY 2011

Sec. Def. to review defense acquisition guidance, including DoDI 5000.02

- **Consider "whether measures of *Quality* and *technical performance* should be included in any EVMS."**
- **Submit report to the Congress by Sept. 27**
  - **Changes in acquisition guidance, if needed**
  - **Actions to implement changes**

Pertinent articles:

- ***Defense AT&L Magazine*, May/June 2011: "Path to EVM Acquisition Reform**
- **DoD *Journal of Software Technology*, August 2011: "Improving the Quality of EVM Information"**

DoD Need: Integrated Testable Requirements

Memo: Test & Evaluation of DoD Programs (1)

1. **Improve relationship among testing, require-ments and program management communities**
2. **Well defined, testable requirements**

- Requirements development must be informed by technical feasibility and ***rigorous trade-off analysis***.
- Define requirements in ways that are clear and ***testable***…should be achieved as early as possible.
- Define requirements in ways that provide *meaningful* ***increments of operational capability.***
- Define requirements in ways that enable efficient program ***execution***.

(1) 6/3/2011, signed by USD for AT&L, Ashton Carter and Director OT&E, J. Michael Gilmore.

Deficiencies in Use of EVM

GAO Report	Title	Findings and Recommendations
08-448	Defense Acquisitions: Progress Made in Fielding Missile Defense, but Program Short of Meeting Goals (Missile Defense Agency (MDA)	<u>Deferred Functionality</u> MDA *did not track* the cost of work *deferred* from one block to another. • Cost of first block understated. • Cost of second block overstated.

Deficiencies and Loopholes in ANSI-748

EVMS Quality Gap

EVMS Standard, Federal Acquisition Regulation (FAR) and Defense FAR Supplement (DFARS) are deficient:

No **guidance or requirement to link**

- **Reported EV**

  with

- **Progress toward meeting *Quality/technical performance requirements***

EVMS Quality Gap

Quality Gap

EVMS Standard shortfall (3.8):

- **"EV is..measurement of *quantity* of work"**
- ***"Quality* and *technical* content of work performed are *controlled by other means" !?***

EVMS Quality Gap

EVMS Standard shortfall (Guideline 2.2b):

Identify (ID)

- **physical products**
- **milestones**
- **technical performance goals**

"or"

- **other indicators**

that will be used to measure progress.

Quality Gap

"or" not "and"

Management Reserve (MR) Quality Gap

EVMS loopholes facilitate use of MR for cost overruns:

3.5.4 "MR is held for *unexpected growth* within the currently authorized work scope"

How is MR misused?

1. **Frequent causes of additional testing and rework:**
   - **Unrealistic baseline assumptions**
     - **Low estimates of rework %, software defects etc.**
   - **Failure of design to meet technical requirements**
2. **Initial design work packages reported as "95% complete" based on quantity of work completed, *not technical performance* (3.8)**
3. **MR used to budget additional testing and rework**
4. ***Results: Accurate progress and cost overrun are not reported***

Standards, Models, Guides: Guidance on Quality

Guidance in Standards, Models, and DoD Guides

- Processes for Engineering a System (ANSI/EIA-632)
- Standard for Application and Management of the SE Process (IEEE 1220)
- Capability Maturity Model Integration (CMMI®)
  - CMMI for Development, Version 1.3
  - CMMI for Acquisition, Version 1.3
  - *Using CMMI to Improve Earned Value Management* , 2002
- Guide to the Project Management Institute Body of Knowledge (PMBOK Guide®), 4th Edition

Keystones of Integrated Planning

- ***Technical baselines***
- ***Technical performance***
- ***Success criteria***
- ***SE/quality work products***

DOD Guides: Integrated Planning

DoDI 5000.02, Operation of the Defense Acquisition System (POL) 12/08
Interim Defense Acquisition Guidebook (DAG) 6/15/09
Systems Engineering Plan (SEP) Preparation Guide 4/08
WBS Handbook, Mil-HDBK-881A (WBS) 7/30/05
Integrated Master Plan (IMP) & Integrated Master Schedule Preparation & Use Guide (IMS) 10/21/05
Guide for Integrating SE into DOD Acquisition Contracts (Integ SE) 12/06
Defense Acquisition Program Support Methodology (DAPS) V2.0 3/20/09

DoD: Technical Baselines And Reviews

DoD Policy or Guide	POL	DAG	SEP	WBS	IMP/ IMS	Integ SE	DAPS
Technical Baselines in IMP/IMS (Milestones): • Functional (SFR) • Allocated (PDR) • Product (CDR)		X				X	X
Technical Reviews:							
• Event-driven timing of technical reviews	X	X	X	X	X	X	X
• Success criteria of technical reviews	X	X	X	X	X	X	X
• Include entry and exit criteria for technical reviews in IMP and IMS		X	X			X	X
• Assess technical maturity in technical reviews		X	X	X		X	

DoD: Integrated Plans

DoD Policy or Guide	POL	DAG	SEP	WBS	IMP/ IMS	Integ SE	DAPS
Integrate SEP with: • IMP/IMS • *TPMs* • EVM		X	X		X	X	X
Integrate WBS with • *Requirements specification* • Statement of work • IMP/IMS/EVMS		X		X	X	X	X
Link risk management (including risk mitigation plans), technical reviews, *TPMs*, EVM, WBS, IMS		X				X	X

Technical Baselines

Manage the Technical Baseline

DAG 4.5.1. Systems Engineering Plan

- **Include the system's technical baseline approach**
  - **How the *technical baseline* will be developed, managed, and used to control**
    - ***System requirements***
    - **Design integration**
    - **Verification**
    - **Validation**
  - **Discuss *TPMs and how they will be used to measure progress***

Functional Baseline (DAG)

What

- **Definition of the required system functionality**
  - **Functional and interface characteristics of overall system**
  - **Verification required to demonstrate their achievement**
- **Derived from the Capabilities Development Document (CDD)**
- **Includes**
  - **Detailed functional performance specification for the overall system**
  - **Tests necessary to verify and validate system performance.**

When:

- **Established at System Functional Review (SFR)**
- **Verified at System Verification Review (SVR)**

Allocated Baseline (DAG)

What

- **Definition of the configuration items (CI) making up a system**
- **All functional and interface characteristics allocated from the top level system or higher-level CIs**
- **Derived requirements**
- ***Performance* of each CI in the allocated baseline**
- **Tests necessary to verify and validate CI performance**

When: At each CI's Preliminary Design Review (PDR)

Product Baseline (DAG)

What

Necessary functional and physical characteristics of a CI

- **Selected functional and physical characteristics designated for production acceptance testing**
- **Tests necessary for deployment/installation, operation, support, training, and disposal of the CI**
- **Initial product baseline includes "build-to" specifications for hardware (product, process, material specifications, engineering drawings and software (software module design— "code-to" specifications)**

When:

- **At each CI's Critical Design Review (CDR)**
- **System product baseline established at system-level CDR**

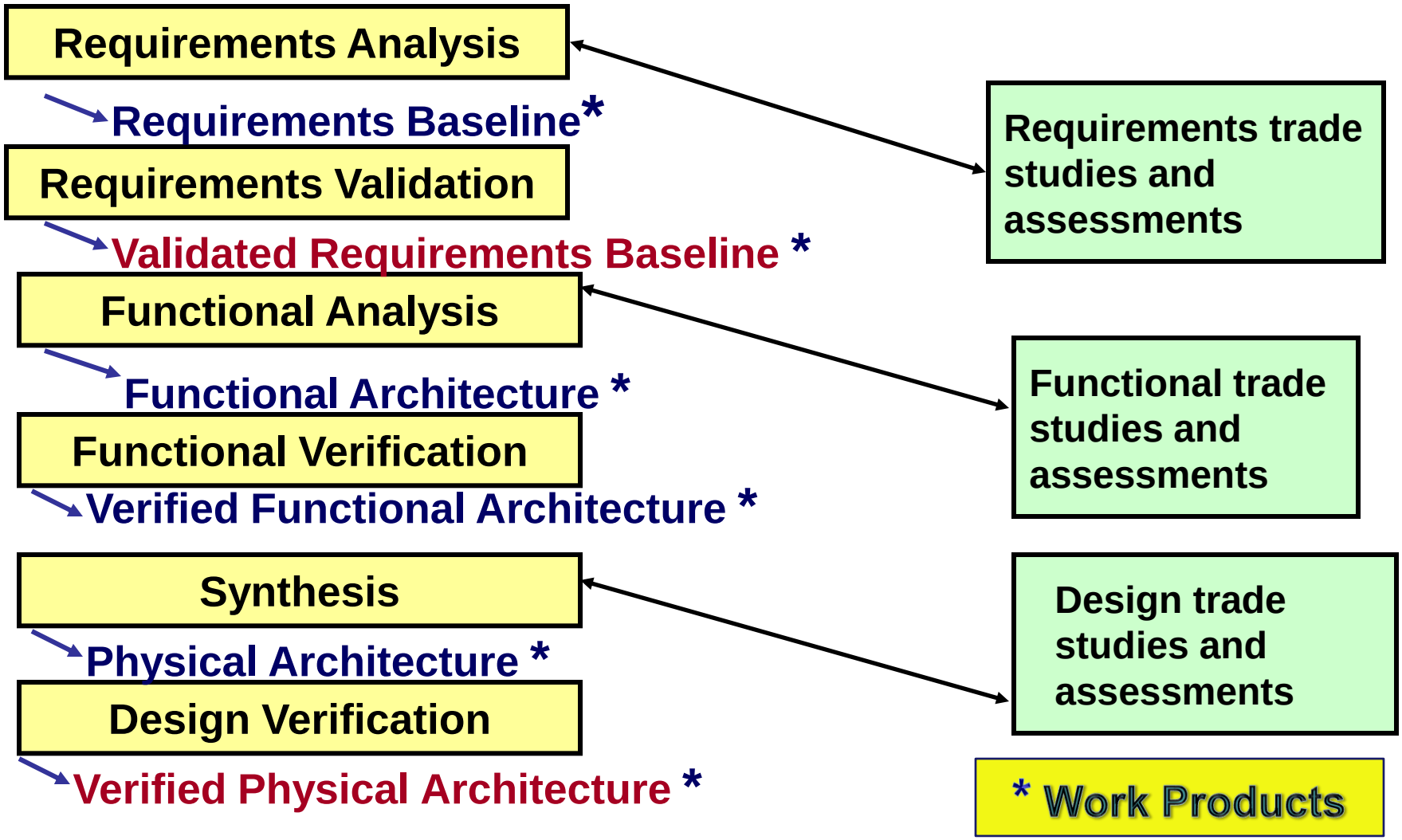
Baseline (CMMI/DAG)

Requirements Development	SG 2: Develop Product Requirements	DAG
SP 2.1 Establish and maintain product and product component requirements, based on customer requirements	Example work products: • Derived requirements • Product requirements • Product component requirements Subpractices 1. Develop requirements in technical terms necessary for product and product component design 2. Derive requirements that result from design decisions	4.2.3.1.6.2 Establish Configura-tion Baselines

SG: Specific Goal

SP: Specific Practice

SE Life Cycle Baselines, IEEE 1220



Technical Baselines

B

C

System Integration

System Demonstration

Design Readiness Review

SFR

PDR

CDR

PRR

DAG:

System Functional Baseline

Allocated Baseline

Product Baseline

Product Baseline

IEEE 1220:

Validated Requirements

Verified Physical Architecture

PMBOK Guide: Performance Measurement Baseline (PMB) including *technical and quality parameters*

Baselines (CMMI/DAG)

Requirements Management	SG 1: Manage Requirements	DAG
SP 1.4 **Maintain bidirectional traceability among the requirements and work products**	**Example work products:** **Requirements traceability matrix (RTM)** **Subpractices** **2. Maintain requirements traceability from a requirement to its derived requirements and allocation to functions, interfaces, objects, people, processes, and work products.** **5. Generate the RTM**	**4.2.3.1.6.2** **Establish Configura-tion Baselines:** **Product baseline;** **necessary functional and physical characteristics of a configuration item**

CMMI: Requirements Management

SG 1 Manage Requirements

SP 1.2
Obtain commitment to requirements

SP 1.4
Maintain bi-directional traceability:
- Requirements
- Plans
- Work products

SP 1.5
Ensure that project plans and work products remain aligned with requirements

Example Work Products:
- Documented comments to requirements and requirements changes.

Example Work Products:
- Requirements traceability matrix

Subpractices:
Identify changes that need to be made to the plans and work products resulting from changes to the requirements baseline

PMBOK® Guide

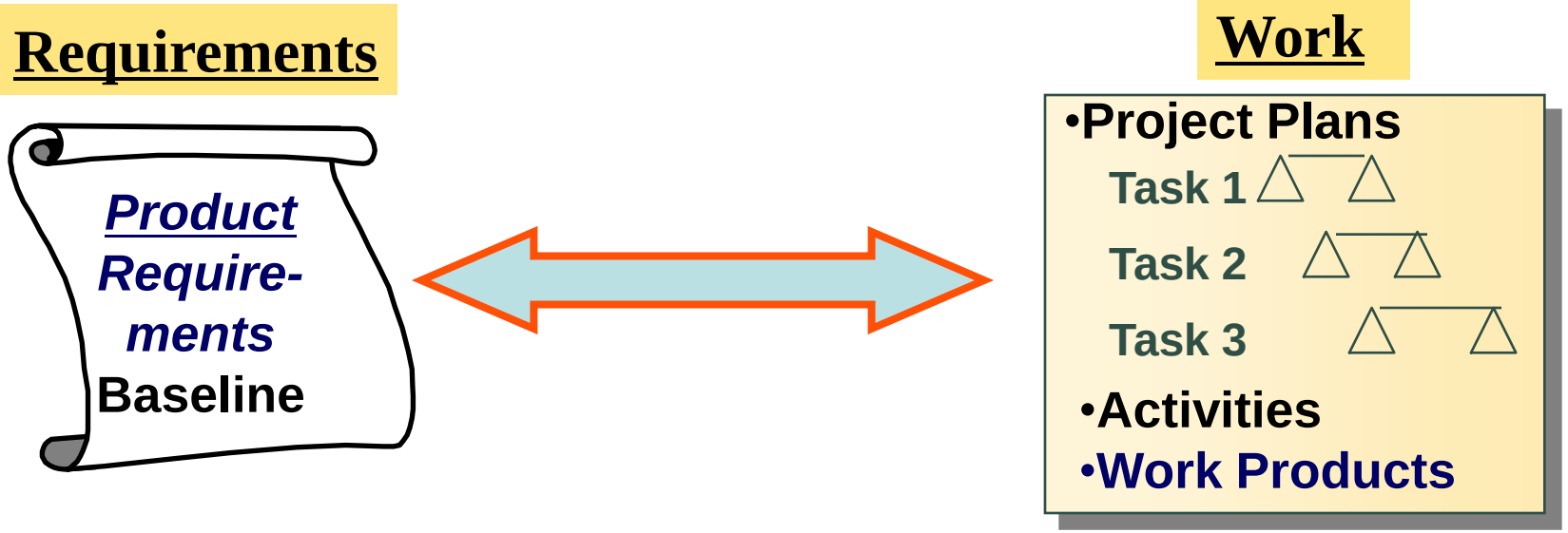
5 Project Scope Management

In the project context, the term scope can refer to

- ***Product scope.*** **The *features* and *functions* that characterize a product, service, or result**
- **Project scope. The *work* that needs to be accomplished to deliver a product, service, or result with the specified features and functions.**

Product Requirements Baseline

- CMMI®, PMBOK Guide® : Traceability and consistency



Source: CMMI Requirements Management Process Area (PA), Specific Practice (SP) 1.5

Technical Performance

TPMs in DAG

DAG:

- **Performance measurement of WBS elements, using objective measures:**
  - ***Essential for EVM*** **and Technical Assessment activities**
- ***Use TPMs*** **and Critical Technical Parameters (CTP) to report progress in achieving milestones**
- **Plan is defined in terms of:**
  - **Expected performance at specific points**
    - **Defined in the WBS and IMS**
  - **Methods of measurement at those points**
  - **Variation limits for corrective action.**

TPMs in DAG

- TPM parameters to be tracked
  - Cost drivers on the program,
  - On the critical path
  - Represent high technical risk items.
- Contract Deliverable
  - Report of TPMs that are traceable to:
    - Needs of the operational user
    - Key Performance Parameters (KPP), Critical Technical Parameters
    - Key system attributes
- Contractor's internal TPMs
  - TPMs at a more detailed level

TPM (CMMI/DAG)

Requirements Development	SG 3: Analyze and Validate Requirements	DAG
SP 3.3 **Analyze Requirements**	**Example work products:** • Requirements defects reports • Key requirements • TPMs **Subpractices** **4. Identify key requirements that have as strong influence on cost, schedule, functionality, risk, or performance** **5. Identify TPMs that will be tracked during the development effort**	**2.1.1.4,** **4.5.6.1** **TPMs**

TPM (CMMI/DAG)

Measurement and Analysis	SG 1: Align Measurement and Analysis Activities	DAG
SP 1.2 **Specify Measures**	**Example work products:** **Specifications of base and derived measures** **Subpractices** **3. Specify operational definitions for the measures..in precise and unambiguous terms**	**4.5.4.2,** **WBS:** **Objective measures..** **essential for EVM…** **integrated with TPMs and CTPs**

TPM (CMMI/DAG)

Project Monitoring & Control	SG 1: Monitor Project Against the Plan	DAG
SP 1.1 Monitor Project Planning Parameters	Monitor actual values of planning parameters against plan Subpractices: Monitor: 1. Progress against schedule 2. Cost 3. Attributes of work products and tasks	4.5.6.1 TPMs and CTPs

Requirements and Product Metrics

IEEE 1220	EIA-632
6.8.1.5 Performance-based progress measurement	4.2.1 Req. 10: Progress against requirements
6.8.1.5 d) Assess • *Development maturity* • Product's ability to *satisfy requirements* 6.8.6 ***Product metrics at pre-established control points:*** • Evaluate system ***quality*** • *Compare* 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)

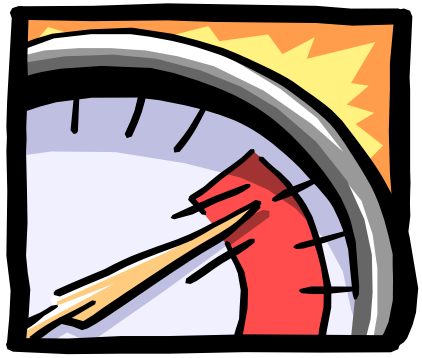
IEEE 1220: 6.8.1.5, *Performance-based progress measurement*	EIA-632: Glossary	CMMI for Development Requirements Development
TPMs are key to progressively assess technical progress	*Predict* future value of *key technical parameters* of the end system based on current assessments	Specific Practice (SP) 3.3, Analyze Requirements Typical work product: *TPMs*
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*	Subpractice: Identify TPMs that will be tracked during development

PMBOK TPM Guidance

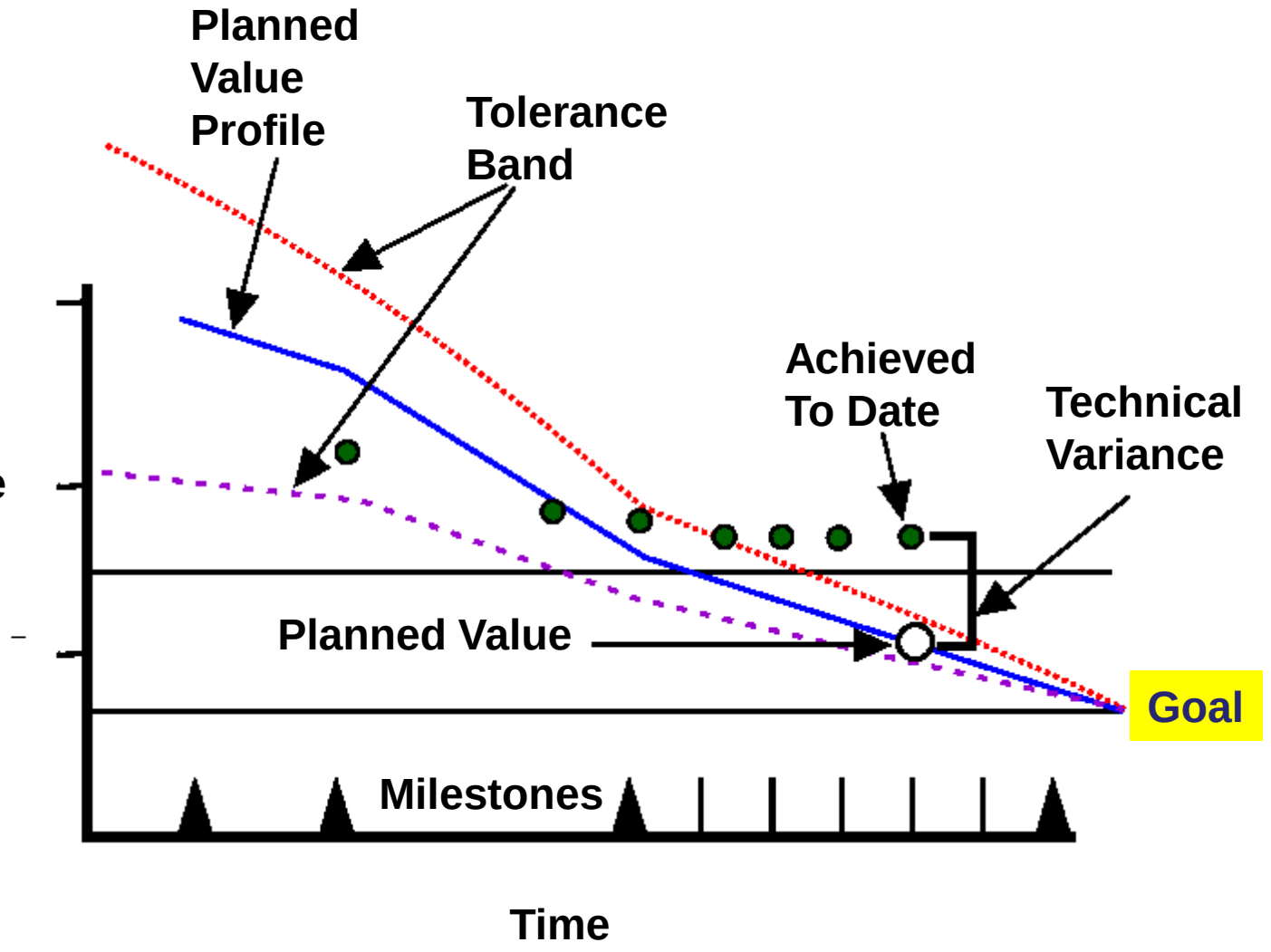
- **Technical performance measurement compares technical accomplishments during project execution to the … schedule of technical achievement.**
- **It requires definition of objective, quantifiable TPMs which can be used to compare actual results against targets (11.6.2.4).**

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



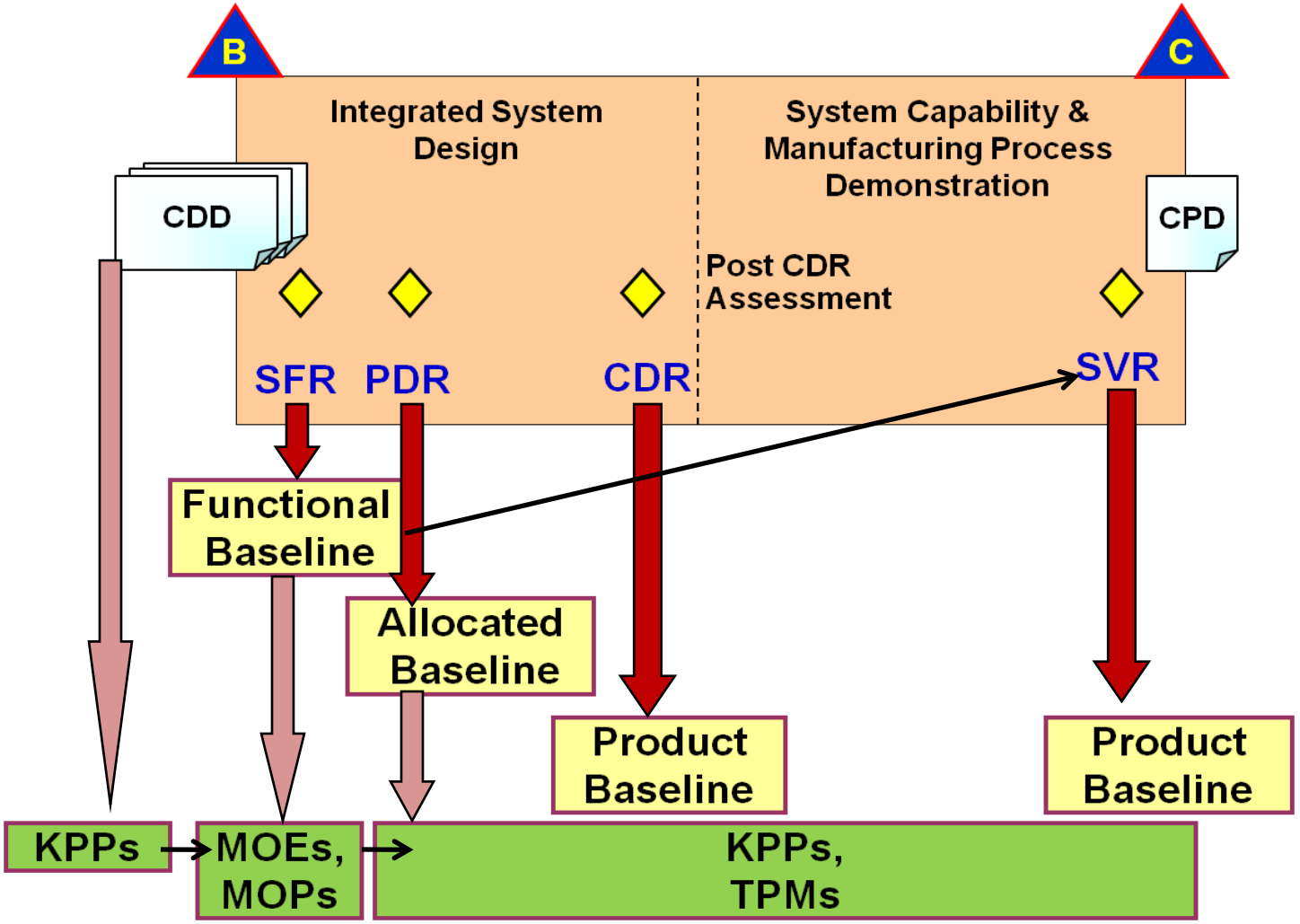
TPM Performance vs. Baseline



Derivation and Flowdown of TPMs

Document, Baseline, IMS, EVM	Parameter
CDD	Key Performance Parameter (KPP)
Functional Baseline	Measures of Effectiveness (MOE)
Functional Baseline	Measures of Performance (MOP)
Allocated Baseline	TPM
IMS	TPM Milestones and Planned Values
Work packages	TPM-based % complete criteria

Technical Reviews, Baselines, Measures



Success Criteria

Success Criteria (CMMI/DAG)

Requirements Development	SG 3: Analyze and Validate Requirements	DAG
SP 3.2 **Establish a Definition of Required Functionality**	**Example work products:** • Functional architecture • Activity diagrams and use cases **Subpractices** 1. Analyze and quantify functionality required by end users 2. Allocate functional and performance requirements to functions and subfunctions	**4.2.3.1.6.2** **Establish Configura-tion Baselines -** **SFR success criteria**

PDR Success Criteria

DAG 4.3.2.4.2.3 (partial)

- Preliminary design satisfies the CDD
- System allocated baseline established and documented to enable detailed design to proceed with proper configuration management
- Program schedule executable (technical/cost risks)
- Producibility assessments of key technologies completed
- Program executable with
  - Existing budget
  - Approved system allocated baseline
- Risks known and manageable for testing

Note: Software success criteria discussed in later section

CDR Success Criteria

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

Success Criteria (CMMI/DAG)

Requirements Development	SG 2: Develop Product Requirements	DAG
SP 2.2 **Allocate product component requirements**	**Example work products:** • Requirement allocation sheets • Design constraints • Derived requirements **Subpractices** 1. Allocate requirements to functions 2. Allocate requirements to product components	**4.2.3.1.6.2** **Establish Configura-tion Baselines –** **PDR, CDR Success Criteria**

SE/Quality Work Products

- Establish milestones on IMS
- Discrete EV measurement, not LOE

Validated Requirements (Functional) Baseline

IEEE 1220, (6.1, 6.2): Work Products

- **Customer expectations**
- **Project, enterprise and external constraints**
- ***Operational scenarios***
- ***MOEs***
- **Interfaces**
- ***Functional requirements***
- ***MOPs***
- **Modes of operation**
- **Design characteristics**
- **Documented trade-offs**

CMMI Example
SE Work Products

Requirements Development PA

- **Prioritized customer requirements**
- **Customer constraints on the conduct of verification**
- **Customer constraints on the conduct of validation**
- ***Activity diagrams and use cases***
- **Derived requirements**
- **Relationships among derived requirements**
- ***Product requirements***
- **Definition of *required functionality* and *quality attributes***
- ***TPMs***

CMMI Example
SE Work Products

Requirements Management PA:

- ***Requirements traceability matrix (RTM)***

Verification PA:

- ***Verification methods*** **for each selected work product**
- ***Verification criteria***
- ***Exit and entry criteria for work products***
- **Verification results**

Measurement and Analysis PA:

- ***Measurement objectives***
- ***Specifications of base and derived measures***

CMMI Example
SE Work Products

Technical Solution PA:

- **Documented relationships between *requirements* and product components**
- **Product component design**
- **Interface specification criteria**
- **Implemented design**

Guidelines for Performance-Based EVM (PBEV)

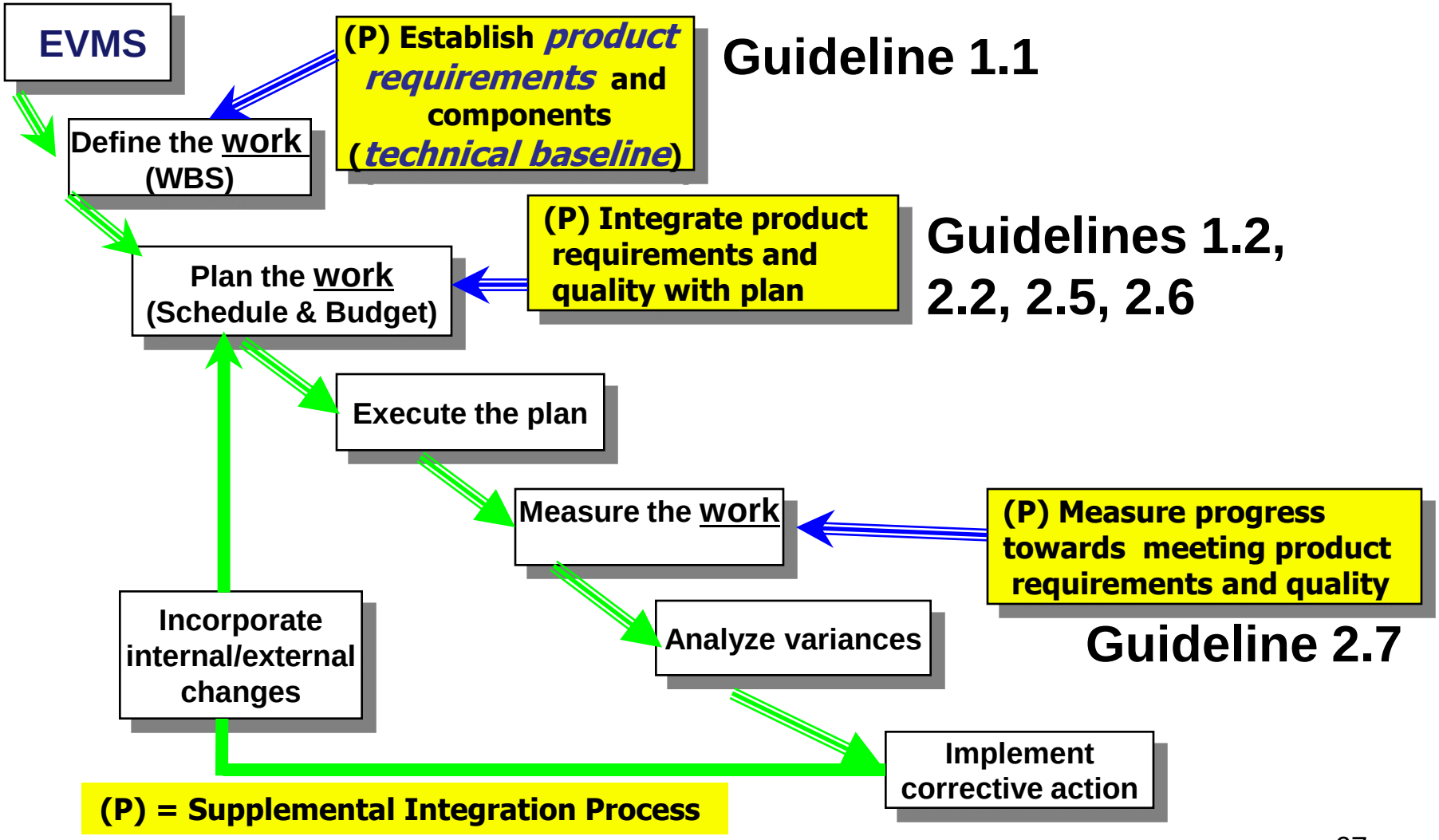
16 guidelines distilled from standards and models

Why Use More EV Guidelines?

- Link EV to technical performance, design maturity and *quality*
- *"Quantify quality"* measures
  - Functionality: Percent of product requirements met (weighted)
  - Technical performance achieved
  - Plan and track rework
- *Measure quality* of work products
- *Status quality* in requirements traceability matrix
- Address quality in variance analyses

EV without Quality has less management value

PBEV Guidelines Augment EVMS



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.**

Note: All 16 guidelines cross-referenced to SE standards and CMMI in article, "Performance-Based Earned Value", in DOD *CrossTalk*, 8/2005 General discussion of PBEV in "Applying EVM to Software-Intensive Programs" in *Software Tech News*, 4/2009.

PBEV Guidelines

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

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***

PBEV Guidelines

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

2.7 Compare

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

for achieving progress towards meeting *product requirements*

LEAN Benefits

- Minimize costs; measurement costs money
- Fewer work packages with right base measures
  - Requirements-driven plan
  - TPMs
  - SE and technical work products

Practical Application

Technical Performance Measures

Example (Ex) 1: EV Based on Drawings and TPMs

- SOW: Design a subsystem with 2 TPMs:
  - Maximum (Max.) weight
    - Planned Value (PV): 200 lb. (May)
  - Max. diameter
    - PV: 1 inch (when 80% drawings complete, April)
- Enabling work products: 50 drawings
- BAC: 2000 hours
  - Drawings: 40 hours/drawing @ 50 2000
  - If TPM PVs *not* met on schedule:
    - Negative adjustment to EV
      - Weight: -100
      - Diameter -200

Ex 1: EV Based on Drawings and TPMs

Schedule	Total	Jan	Feb	Mar	Apr	May	Total
	Drawings						
Drawings/ period	50	8	10	12	10	10	50
Meet requirements:							
Weight	1					▲	
Diameter	1				▲		

Ex 1: Status

Date	April 30	May 31
Drawings completed	41	49
Weight met	No	No
Diameter met	Yes	Yes

Ex 1: EV Based on Drawings and TPMs

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				0	-100	
Net EV cum	360	760	1160	1640	*1860*	*1860*

SV = - 140

Ex 1: Variance Analysis

May variance analysis (drawings and requirements):

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

TPMs Work for Software Too

Same technique works for hardware:

- **Substitute computer software units for drawings**
- **Use SW TPMs such as:**
  - **Defect density**
  - **Throughput**

TPM at Higher WBS Level

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

Ex 2: TPM at Higher WBS Level

Assumptions:

- **Component in Example 1 is one of four components that form a subsystem**
- **Subsystem's TPM objective is 4000 lb.**
- **Systems Engineering Plan 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

Comp/ Work Pkg	TPM PV (lb)	Comp Mile-stone	Comp EV Penalty	Sub Mile-stone	Sub EV Penalty	Bud-get
1	200	April	-100	May	-50	
2	1000	April	-500	May	-250	
3	2000	May	-1000	May	-500	2000
4	800	May	-400	May	-200	
Total	4000		-2000		-1000	

Ex 2: Component 3

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					- 1500	
Net EV cum	360	760	1160	1640	*460*	

Component: -1000
Subsystem: -500

Rework

Ex 3: Negative EV for Rework in Same Work Package

- SOW: 50 drawings to design a product
- PMB: 2000 hours over 5 months
- Rework was not planned in a separate work package

- Status at end of 4th month:
  - Behind schedule to complete initial drawings
  - Drawings returned for rework

Lesson: Drawings Returned for Rework Cause Negative EV

Ex 3: Negative EV for Rework in Same Work Package

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		

Negative Adjustments to EV

- **Why make negative adjustments to EV?**
  - **More accurate status**
  - **Earlier warning of real deviations**
  - **More effective variance analysis**

Negative Adjustments to EV

- If change in milestones, # of units etc:
  - Previous progress, as % complete, is no longer accurate
  - CPI, base on old EV, is not current or accurate
  - EAC, based on old CPI, is not current or accurate
  - Estimated completion date may need change

Rework Techniques

- **Technique 1: Interim milestones**
  - **Discrete based on success targets**
  - **Example: Interim Milestones**
    - **Final month: 100% of requirements met**
    - **Final month – 1: 90% of requirements met**
    - **Final month - 2: 85% of requirements met**
- **Technique 2: Negative EV when "completed" work product is returned for rework**
  - **Update cumulative EV based on current technical progress**

EVMS Allows Retroactive Changes

EVMS Guideline 30:

- **Control retroactive changes to …work performed.**
- **…Adjustments should only be made..to *improve the accuracy* of performance measurement data.**

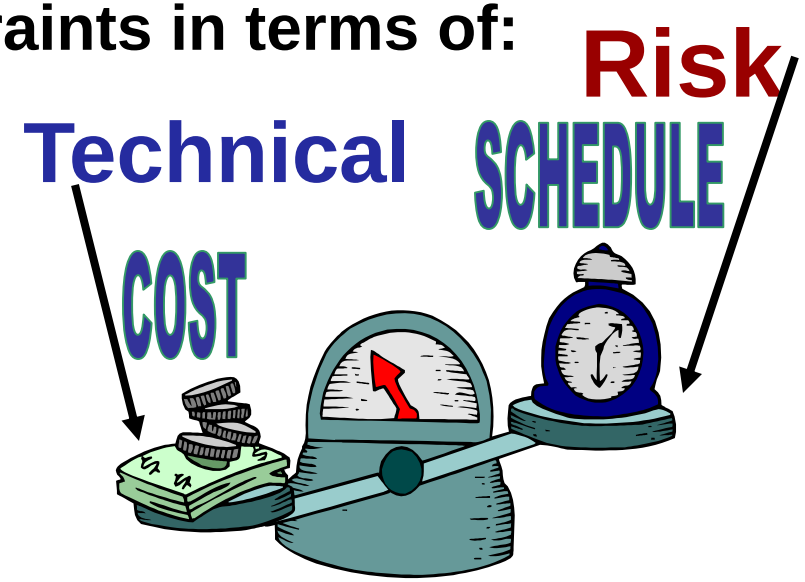
Why Plan Rework Separately?

- **Better knowledge of schedule progress towards *initial* development of requirements, design, code**
  - **– Earlier warning of slip to completion of initial development**
  - **– Better cost variance analysis**
- **During IBR, can determine if sufficient budget and time for rework is included in PMB**
  - **Preclude use of MR for rework**
- **Better cost and schedule variance analysis**

Trade Studies

Trade Studies

- Performed during all phases of the engineering life cycle
- Provide objective foundation to select an approach to the solution of an engineering problem.
- Systems definition: Identify the recommended set of requirements and constraints in terms of:
  - Risk
  - Cost
  - Schedule
  - Performance impacts
- Design solution



Trade Studies and Requirements

- Typical trade results:
  - Select user/operational concept
  - Select system architectures
  - Derive requirements
    - Alternative functional approaches to meet requirements
    - Requirements allocations
  - Cost analysis results
  - Risk analysis results

Trade Study is a Work Product

- 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
    - Measured discretely.

Ex 4 : Trade – Determine Design Solution

- **Total Budget: 1000**
  - **Test and evaluate 4 candidates: 600**
    - **150 per candidate**
      - **Milestone (MS) 1, test setup: 25**
      - **MS 2, Tests completed: 75**
      - **MS 3, Test results analyzed 50**
    - **Take EV even if candidate discarded before test complete**
  - **Down select to 2 candidates, 5th month: 150**
  - **Document final recommendation: 250**
- **Period of Performance: 6 months**

Ex 4 : Trade – Determine Design Solution

PMB:

Activity	Jan	Feb	Mar	Apr	May	June	Total
Candidate 1	25	75	50				150
Candidate 2	25	75	50				150
Candidate 3		25	75	50			150
Candidate 4		25	75	50			150
Select 2 candidates					150		150
Make recommendation						250	250
Current BCWS	50	200	250	100	150	250	1000
Cumulative BCWS	50	250	500	600	750	1000	1000

Ex 4 : Trade – Determine Design Solution

- **Project on schedule until candidate 2 failed in Feb, after completing 50% of test**
- **CPI = 1**
- **A new candidate, # 5, was added on March 1**
- **Down-select to 2 candidates and final document slip 2 months on March 1**
- ***Problem 4a: Prepare Feb cumulative performance report (Ignore actuals)***
- ***Problem 4b: Develop internal replan for March forward, with revised base measures of EV***

Ex 4a, Trade Study
Feb Worksheet

Activity	Jan	Feb	Mar	Apr	May	June	Total
Candidate 1 BCWS	25	75	50				150
Candidate 2 BCWS	25	75	50				150
Candidate 3 BCWS		25	75	50			150
Candidate 4 BCWS		25	75	50			150
Subtotal	50	200	250	100			600
Select 2 candidates					150		150
Make recommendation						250	250
Current BCWS	50	200	250	100	150	250	1000
Cumulative BCWS	50	250	500	600	750	1000	1000
Cum. BCWP	50						

Ex 4b, Trade Study
March Replan

Activity	Jan	Feb	Mar	Apr	May	June	July	Aug	Total
Candidate 1 BCWS	25	75	20						120
Candidate 2 BCWS	25	75	20						120
Candidate 3 BCWS		25	75	20					120
Candidate 4 BCWS		25	75	20					120
Candidate 5 BCWS			60	60					120
Subtotal	50	200	250	100					600
Select 2 candidates					150				150
Make recommendation						250			250
Current BCWS	50	200	250	100	150	250			1000
Cumulative BCWS	50	250	500	600	750	1000			1000
Cum. BCWP	50	300							
Actuals ETC	50	263							

Hint: Must allocate budgeted cost of work remaining to 5th candidate.

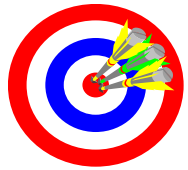
Discrete Earned Value for SE Requirements Management Activities

Requirements Management – Not Level of Effort (LOE)

- **LOE: Unmeasured effort of general nature without a deliverable end product**
  - **Supervision, administration**
- **Requirements Management (RM) outputs are**

  Measurable work products
  - **Validated requirements**
  - **Allocated requirements**
  - **Verification document (test procedure)**
  - **Verified requirements (Verification Cross Reference Index)**

Method



- **Base EV on progress of**
  - **Enabling work products (drawings, code)**
  - **RM tasks and work products**
- **Use Requirements Traceability Matrix**
  - **Set milestones for RM work products**
  - **Measure progress vs. plan**
- **Compare RM EV with total project EV**
  - **SE progress is like a tracking stock for the whole program**
  - **Red Flag: if WBS product progress > SE progress**

Ex 5: Requirements Management (RM)

- Discretely measure SE RM tasks
- Use RTM to control plan

% of Budget	RM Task
15	Define
15	Validate
15	Determine verification (ver) method
0	Approve
20	Allocate
15	Trace to test procedure (ver document)
0	Test
20	Verify

- Key indicator of project performance

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%
Component									
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

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	
BCWP cumulative		0	36	36	60	72
BCWS cumulative		36	60	84	108	156
Schedule Variance		-36	-24	-48	-48	-84

IT/Software Progress Measurement Issues

- DoD Guidance
- Base measures of EV
- Rework
- Deferred functionality
- Trade studies

DoD Software Guidance

Guidance in Models and DOD Publications

- **Capability Maturity Model Integration (CMMI®)**
  - ***Using CMMI to Improve Earned Value Management*, 2002**
- ***Practical Software and Systems Measurement: A Foundation for Objective Project Management, v. 4.0 (PSM);* sponsored by U.S. Army**
- **Naval Air Systems Command (NAVAIR)**
  - ***Using Software Metrics & Measurements for Earned Value Toolkit* , 2004**
- ***USAF Weapon Systems Software Management Guidebook***

Success Criteria for Requirements Status

Category: Work Unit Progress Measure: Requirements Status Collect for Each: Requirements Specification	
Data Item	**Completion Criteria**
• *Total # of Requirements* • # of Requirements Traced to: • Detailed Specifications • Software Components • Test Specifications • *Tested Successfully*	• Completion of Specification Review • Baselining of Specifications • *Baselining of Requirements Traceability Matrix* • Successful Completion of all Tests, in Appropriate Test Sequence

Success Criteria for Incremental Capability

Category: Incremental Capability Measure: Increment Content – Functions Collect for Each: Function	
Data Item	**Completion Criteria**
• *# of Functional Requirements* • # of Functional Requirements *Successfully Implemented*	• Successful testing • Successful integration

USAF Weapon Systems Software Management Guidebook

3.6.2 Requirements and Incremental Software Development

b. Map/allocate the requirements into all planned builds.

- **Failure to do so will increase likelihood that**
  - **Functionality will migrate to later builds**
  - **Initial delivery will not meet user expectations**
  - **Unplanned builds will become necessary**
  - **Delivery of full functionality will be delayed.**

Rework

To ensure adequate budget and period of performance:

- Planning assumptions for rework should include:
  - Planned rate or number of defects expected
  - Budgeted resources to fix the defects, including retest

Rework

- Plan rework in separate work packages from the initial development of
  - Requirements
  - Design
  - Code
- All incremental builds must include budget and schedule for rework to correct defects that were found in the current and previous builds

SW Base Measures of EV

Initial Development Measures

Design:

- $ – Base EV on
  - # Enabling work products **and**
  - # Requirements met
- $ – Example:
  - # Components designs completed **and**
  - # Requirements met traced to components

$ - Recommended Measure

Initial Development Measures

Implementation: Code and test

- **Source Lines of Code (SLOC) coded**
- **# components implemented, component tested, configuration item tested**
- **# of tasks completed and functionality achieved**

Initial Development Measures

- **Integration and test planning**
  - **# requirements traced to test specifications**
  - **# test cases**
  - **# use cases**

SW Rework

Rework of Requirements and Software

– **S/W quality: problems, defects**
  - **# problem reports reported**
  - **# problem reports resolved**
  - **May indicate EAC problems, but not progress**

– ***OVERALL TEST SUCCESS*:**
  - **# test cases attempted**
  - **# test cases passed**
  - ***# requirements tested successfully or verified by inspection***

Deferred Functionality

Incremental Software Capability

- Document baseline content of each build
  - # functional requirements
- Establish build milestones and completion criteria (# functional requirements)
- Establish work packages and EV metrics for builds
- Take EV based on enabling work products and functionality *achieved*
- Account for deferred functionality

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 6: Deferred Functionality

SOW: Software Requirements in 2 Builds:

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

Ex 6: SW Build Plan

Plan and Performance	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Total
Build A							
Planned Reqs met	25	25	25	25	0	0	100
PV/Req	5						
PV - cur	125	125	125	125			500
PV - cum	125	250	375	500			
Build B							
Planned Reqs met				20	20	20	60
PV/Req	5						
PV - cur				100	100	100	300
PV - cum				100	200	300	

Ex 6: Deferred Functionality Status

Plan and Performance	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Total
Build A							
Planned Reqs met	25	25	25	25	0	0	100
Actual Reqs. Met - cur	20	20	25	25	0	0	90
PV - cur	125	125	125	125	0	0	500
PV - cum	125	250	375	500			500
EV-cur	100	100	125	125			
EV - cum	100	200	325	450			450
Schedule Variance (SV)							
Reqs met - cur	-5	-5	0	0	0	0	-10
SV - cur	-25	-25	0	0			
SV - cum	-25	-50	-50	-50			-50

Corrective Action:

1. Release Build A.

2. Move 10 reqs to Build B.

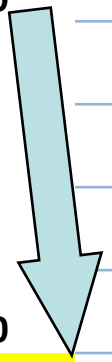
Ex 6: Deferred Functionality Replan

Plan and Performance	Period 3	Period 4	Period 5	Period 6	Total
Close Build A work package:					
Schedule variance:					
Reqs met - cum	-10				
SV - cum	-50				
Build B before replan					
Planned Reqs met		20	20	20	60
PV - cur		100	100	100	300
Plus transfer from Build A					
Deferred Reqs		+ 10			+ 10
PV remaining		+ 50			+ 50
Build B after replan:					
Planned Reqs met		30	20	20	70
PV - cur		150	100	100	350

Transfer PV to 1st month of receiving work package to retain negative schedule variance (behind schedule)

Ex 6: Deferred Functionality Replan

Plan and Performance	Period 3	Period 4	Period 5	Period 6	Total
Build B after replan:					
Planned Reqs met		30	20	20	70
PV - cur		150	100	100	350
Period 4 performance:					
Reqs. Met - cur		20			
EV – cur		100			
SV		-50			



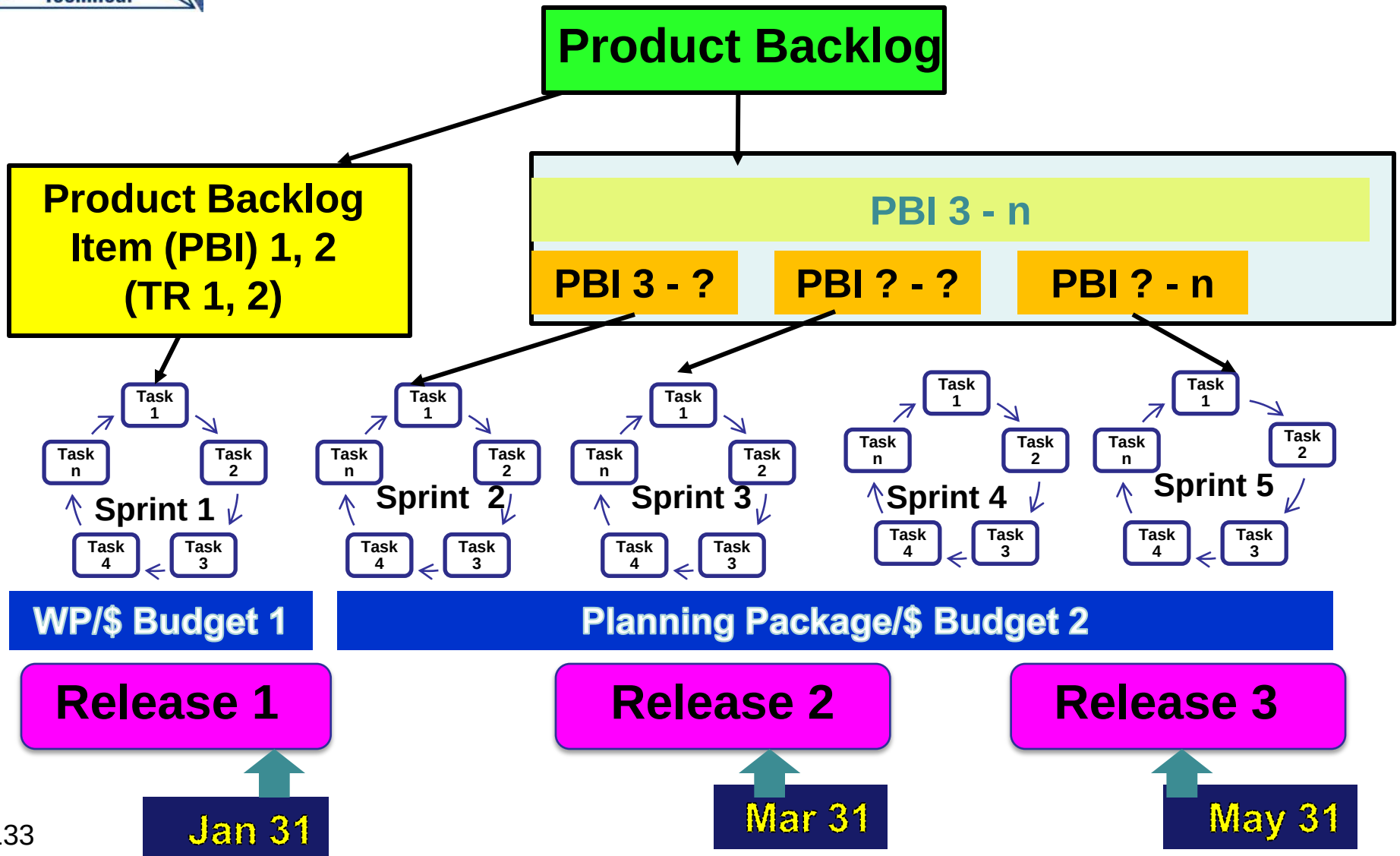
The work package will still be behind schedule at the end of Period 4 if only the original 20 requirements are met

Agile Methods and EV

Agile Methods Characteristics

- Next iteration of work is detail planned in work package (WP)
- Product burndown is a planning package for remaining product burndown items or features
- Features often deferred from the current iteration to the product burndown
- Features and priorities frequently revised

Agile Method



Agile Focus on Near Term May Break Link with PMB

Giving full credit to meeting monthly goals

- **May break link with the PMB**
- **Lose track of progress of plan to satisfy requirements**

Agile Baseline Challenge

Baseline maintenance considerations

- **Most features/PBIs are derived requirements**
  - **Derived from higher level functionality**
  - **Features changes usually *do not* change contract scope or total budget**
- **Maintain PMB and technical baseline**
- **Account for deferred features**
  - **Transfer budget with SOW**
  - **Maintain schedule variance (SV)**

Agile EV Replan Guidance

Internal replanning guidance (a):

- **Hold PMB despite changes to PBI burndown**
  - **Hold baseline finish dates of major releases**
  - **Hold cumulative BCWS at major milestones**
- **Transfer budget for deferred PBIs to first period of next iteration/sprint**
- **Maintain reported schedule variances**
- **Reallocate remaining EV to remaining PBI tasks (including delta PBIs) after each iteration**
- **Revise EAC, compare to funding, reprioritize**

(a) Additional information in "Agile Earned Value and the Technical Baseline" in *Software Tech News*, Sept. 2009 (now called Journal of Software Technology)

Acquisition Management

Acquisition Management

Ensure Contractors Integrate Technical Performance/Quality with EVM

Guidance from:

- **CMMI for Acquisition (ACQ)**
- **AF Space Command-Space and Missile Systems Center/Aerospace Corp. Report**

CMMI-ACQ

Acquisition Technical Management

SP 1.1 Subpractices

3. Identify the quality and functional attribute requirements to be satisfied by each selected technical solution
   - Use a traceability matrix to identifying the requirements for each selected technical solution and relates requirements to work products
4. Identify analysis methods to be used for each selected technical solution
   - Simulations, prototyping, architectural evaluation, demonstrations

Space and Missile Systems Center (SMC)

Systems Engineering Requirements and Products

The Aerospace Corporation Report, TOR-2005(8583)-3, Rev A

- **Contractually binding requirements defined in terms of required SE products and required attributes of those products**

THE AEROSPACE CORPORATION

SMC SE Products: Design Solution

4.2.3.1 Required SE Products:

- **Validated, approved, and maintained (design-to) baseline**
  - **In specifications and interface documents**
  - **Grouped by each system element such as**
    - **Segment**
    - **Subsystem**
    - **Component (hardware and software)**

SMC Shall:
Plan the SE Effort

4.2.12.1 Planning

4.2.12.1.1 Required SE Products

- **In IMP: SE accomplishments, accomplishment criteria, narrative**
- **IMS: tasks**
- **EVMS: work packages**

SMC Shall:
Plan the SE Effort

4.2.12.1 Planning

4.2.12.1.1 Required SE Products

- **In IMP: SE accomplishments, accomplishment criteria, narrative**
- **IMS: tasks**
- **EVMS: work packages**

SMC Shall: Monitor Progress Against the Plan

4.2.12.2 Monitoring

Contractor *SHALL* monitor progress against plan to validate, approve, and maintain each baseline and functional architecture

4.2.12.2.1 Required SE Products

- **Documented SE assessments linked in database to initial plans**
- **Results of each iteration to include tradeoffs**

4.2.12.2.2 Required Product Attributes

a. Each documented assessment includes:

- ***TPMs*, metrics**
- **Metrics and technical parameters for tracking that are critical indicators of technical progress and achievement**

Acquisition Tips

- Require SE best practices in Request for Proposal (RFP)
- Confirm contractor's proposal includes integration of SE with EVM
- Verify integration in IBR
- Confirm achievement of success criteria in technical reviews
- Monitor consistency and validity of status reports, variance analyses, EAC

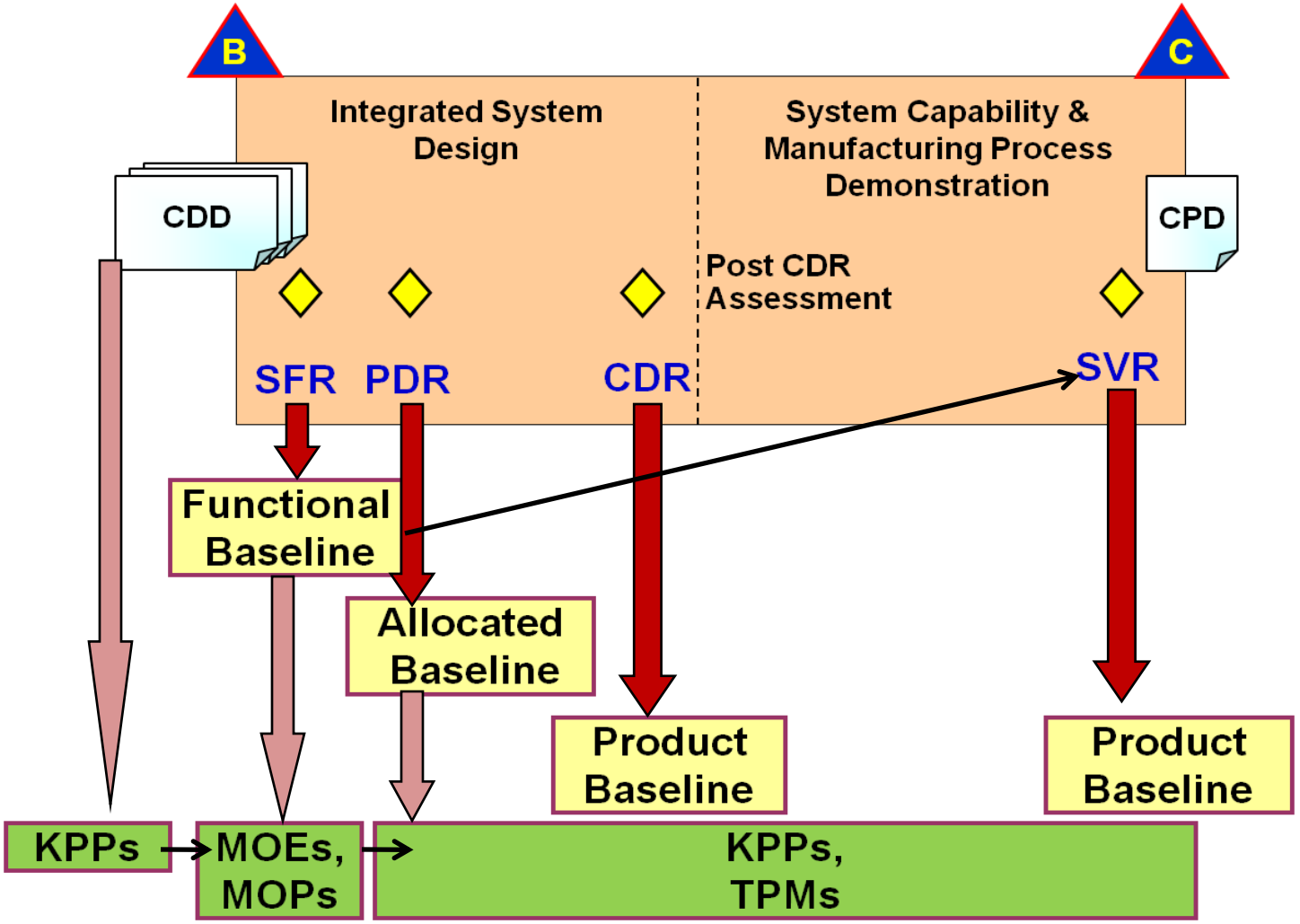
IBR: SE Implementation Review

- Requirements management and traceability
- Milestones for SE requirements work products by WBS
  - Derived requirements
  - Definition of required functionality and quality attributes
  - Verification methods and criteria
- Milestones for establishing product metrics
  - SFR: MOEs, MOPs defined
  - PDR: TPMs defined

IBR: SE Implementation Review

- Milestones with technical maturity success criteria
  - TPM planned values
  - Meeting requirements
  - Percent of designs complete
- Define entry and success criteria for event-driven technical reviews/IMP events
  - Revise/clarify criteria for CDR and subsequent events based on
    - Knowledge of revised and derived requirements to be met
    - TPM planned values
- Flow down of SE milestones to work packages
- Define base measures of EV

Technical Reviews, Baselines, Measures



Framework for Process Improvement

Process Improvement Goal

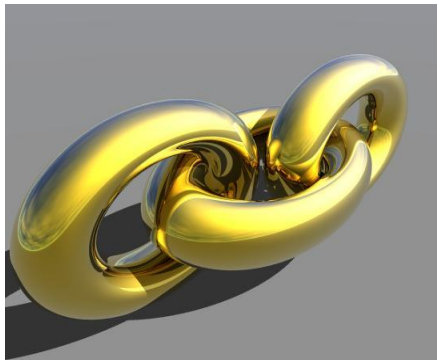
EVMS

SE

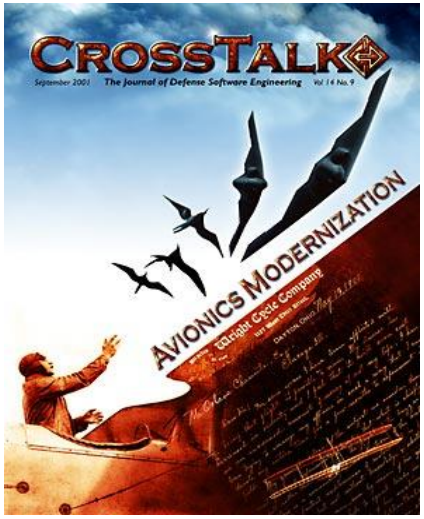
Integrated Planning

Close the EVMS Quality Gap

- PMB includes technical/quality parameters
- Insightful IBRs and technical reviews
- *Valid* contract performance reports
  - Objective technical/schedule status
  - Credible EAC
- Early detection of problems
  - Program performance
  - EV measurement and compliance
- Consider revisions to
  - DFARS
  - DoDI 5000.02



Resources Online



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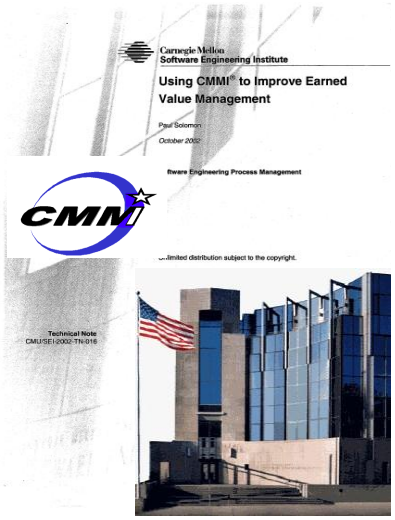
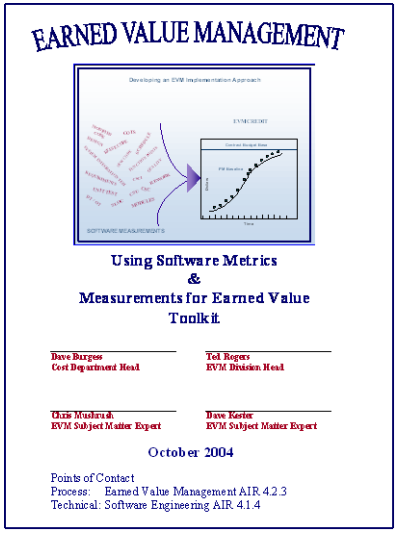


SEI



NAVAIR

DOD DAU

ICFAI U. Press, India

PMI Community of Practice

"Measurable News"

SoftwareTech NEWS

DoD Data & Analysis Center for Software

www.PB-EV.com

Process Improvement Resources

Book includes
- **Examples**
- **Templates**
- **Tips**
- **Standards**
- **Acquisition guidance**

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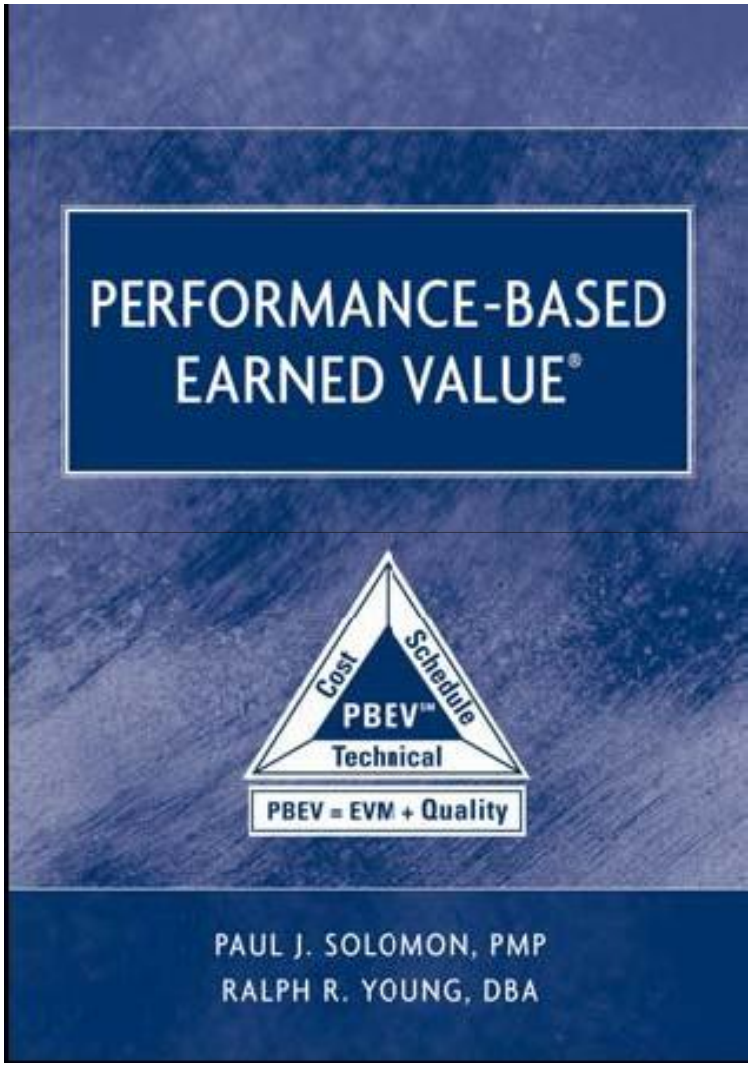

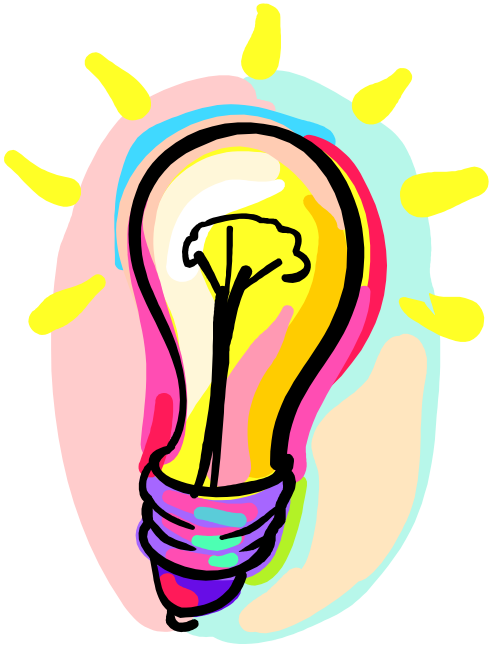

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References

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Acronyms

EVM: Earned Value Management
CPI: Cost Performance Index
PBI: Product Backlog Item
PMB: Performance Measurement Baseline
PV: Planned Value (for a TPM)
RTM: Requirements Traceability Matrix
SE: Systems Engineering
SEP: Systems Engineering Plan
TPM: Technical Performance Measure or Measurement