The Society of Cost Estimating and Analysis

Earned Value Management for Cost Estimators

John Driessnack/Dr Neal Hulkower

Presented by the Washington Area Chapter of SCEA

Agenda

- 9:00 – 9:15 Introductions & Overview - Lehman
- 9:15 – 10:15 Intro to EVM/Evolving Policy – Driessnack
- 10:15 – 10:45 Break
- 10:45 – 11:15 EVM/Policy continued - Driessnack
- 11:15 – 12:00 1st Soupçon of Statistics – Dr Hulkower
- 12:00 – 1:15 Lunch (On Your Own)
- 1:15 – 2:00 Scheduling and Risk Analysis - Driessnack
- 2:00 – 2:30 2nd Soupçon of Statistics – Dr Hulkower
- 2:30 – 3:00 Break
- 3:00 – 3:30 Estimates part 1 - Driessnack
- 3:30 - 4:00 Estimates part 2 - Dr Hulkower

Intro to Earned Value
Overview

- Section 1. Earned Value Management Concepts
- Section 2. Understanding The Processes
- Section 3. Earned Value Management in Federal Agencies
- MCR Triple Gold Card … reference material

"Creating Customer-Focused Success"

Earned Value Management Concepts

Section 1.

Earned Value Management

Definition

- EVM for program management will effectively integrate the work scope of a program [project] with the schedule and cost elements for optimum program planning and control. The primary purpose of the system is to support program management. The system is owned by the company and is governed by company policies and procedures.

ANSI/EIA 748-98A
Industry Standard
Guidelines for EVM

Some Key Distinctions

Earned Value is the budgeted cost of the work that has been accomplished (budgeted cost of work performed) (BCWP). It is compared against the plan (budget cost of work scheduled) (BCWS) and the actual cost (actual cost of work performed) (ACWP).

Earned Value Management is a program management methodology for managing progress and performance.

Earned Value Management System is the set of program management processes that comprise an integrated systems for managing.

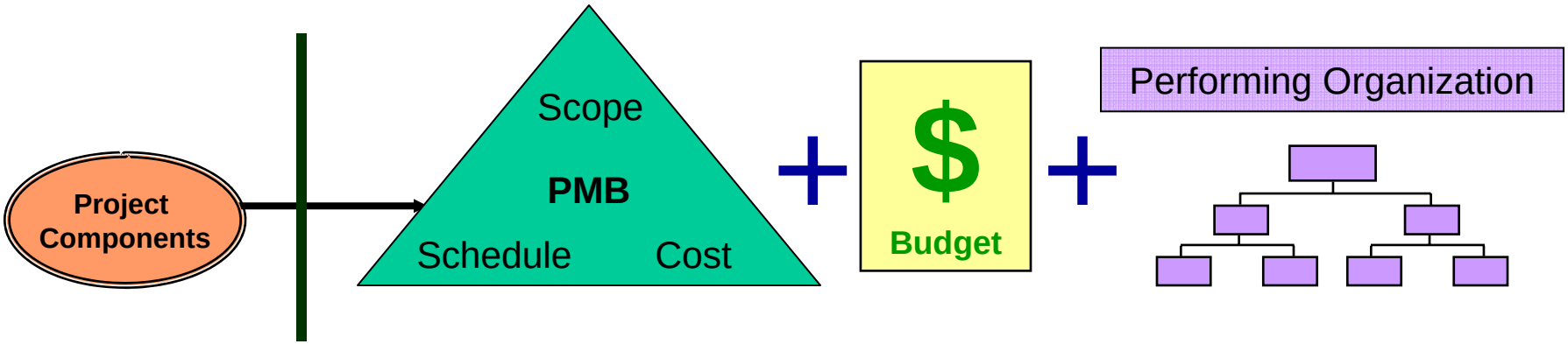
Earned Value Management
Basic Principles

- Break down the work scope into discrete, measurable elements and assign responsibility
- Plan and integrate the scope, schedule and cost into a time-phased plan and control changes to the plan
- Objectively assess progress and accomplishments
- Use actual costs in accomplishing the work
- Analyze variances from the plan, including impacts, and forecast of estimates in completion the work
- Use the information to manage

EVM and Schedule
ANSI/EIA 748-98A emphasis on IMS

- The main purpose of EVMS….”support management”
- Level of Analysis…. “level of detail appropriate”
- Across “work scope … schedule and costs elements
- Program Schedule…network schedules and critical path analysis are proven scheduling techniques that are preferred for some purposes…
- Schedule Performance …schedule variance…represents the quantity, i.e. , the value, of the work that is ahead or behind schedule. The specific activities and events that are contributing to the variance can be identified in program schedules
- …schedule variance metric… used in conjunction with milestone status reports, critical path data, and other schedule status information…
- other techniques, such as critical path analysis, are preferred indicators of long range projections; but a trend analysis of the changes is the schedule variance metric can provide a valid and useful indication of current performance and near-term projections.“

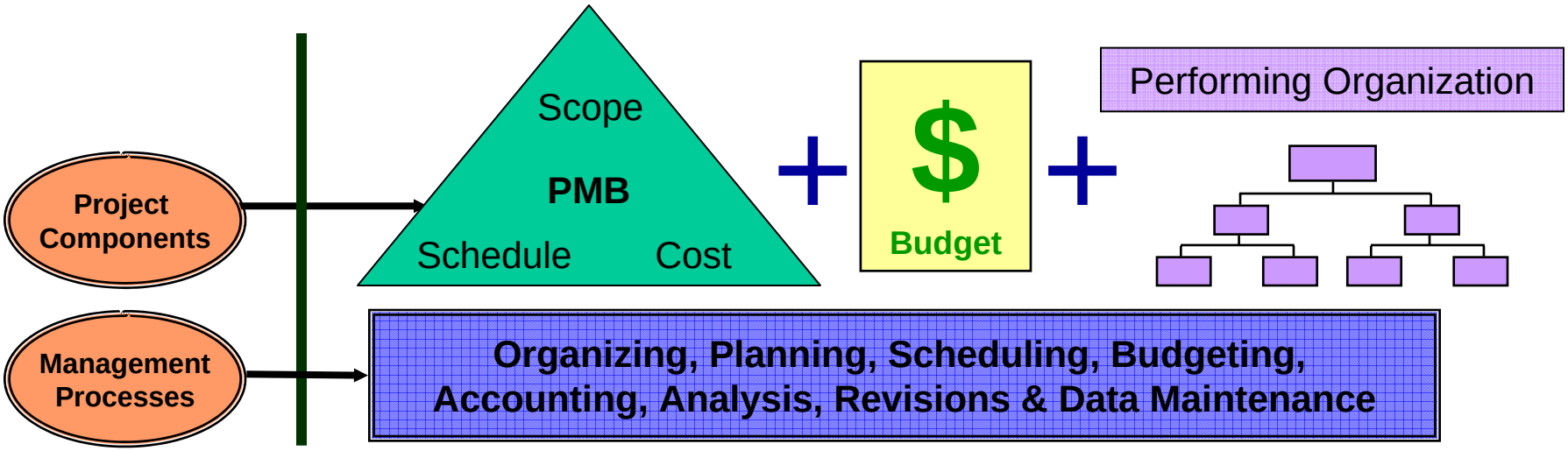
Earned Value Management Context For Programs and Projects



EVM does not exist in isolation. It must be applied to some effort (work)(a project or program) that requires management.

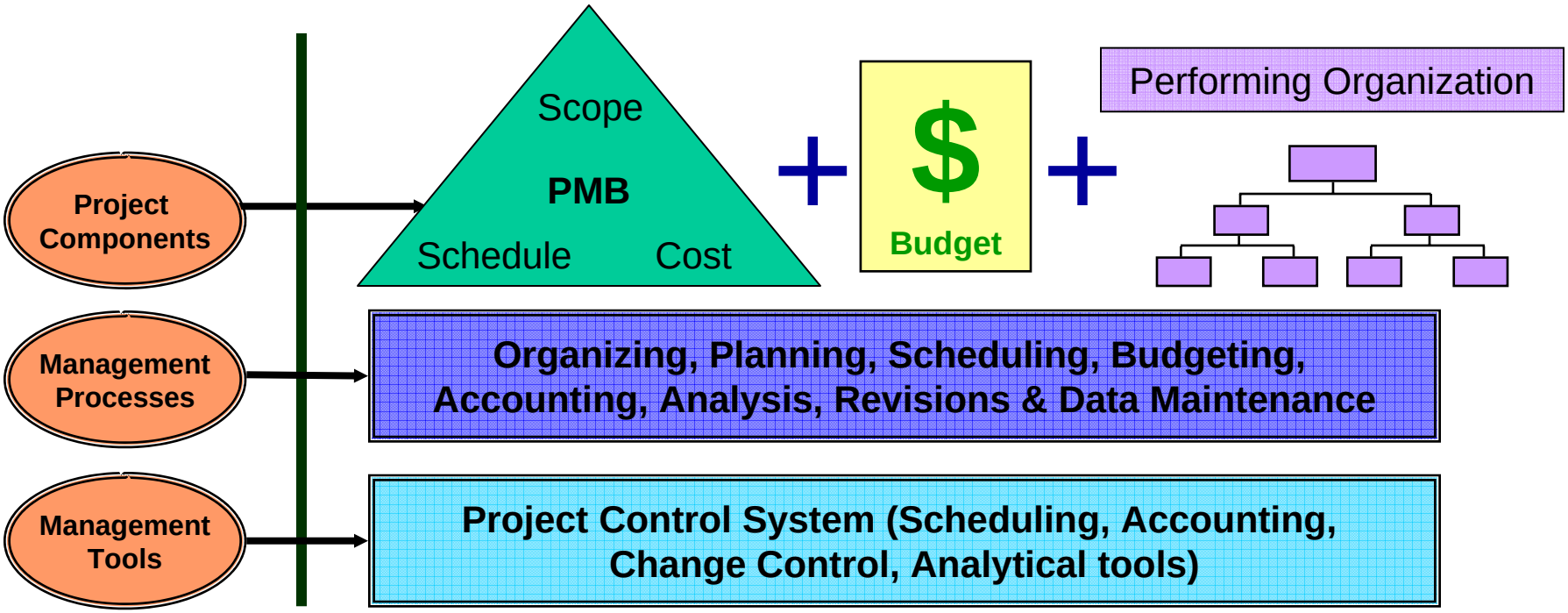
No project – no need for EVM!

Earned Value Management Context For Programs and Projects



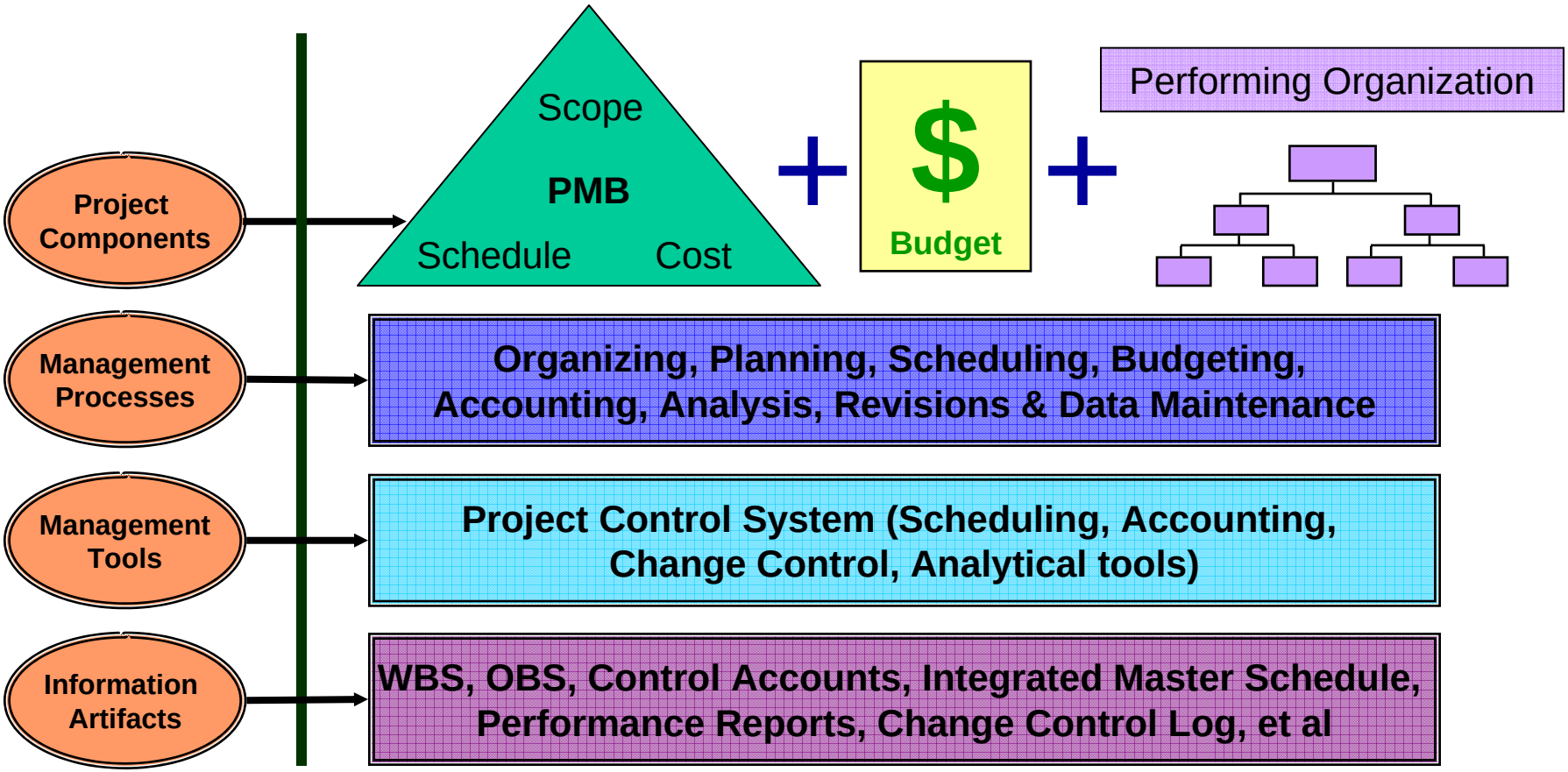
EVM is an integrated set of processes used to manage a project or program. Many of these processes may already exist within an organization, but usually have not been integrated.

Earned Value Management Context For Programs and Projects



Organizations employ tools that facilitate the operation of the processes. The tools themselves do not comprise the system. They are merely the instruments.

Earned Value Management Context For Programs and Projects



The output of the processes used to manage programs are artifacts that comprise the plan, measures progress and controls the program.

"Creating Customer-Focused Success"

Understanding The Processes

Section 2.

ANSI/EIA 748 Earned Value Management Guidelines

- The guidelines contained in the standard are organized into five process groups each comprising multiple guidelines
- EVM Process Groups
  - Organizing
  - Planning, Scheduling and Budgeting
  - Accounting Considerations
  - Analysis and Management
  - Revisions and Data Maintenance
- This section will explore the guidelines and the meaning behind them in greater depth

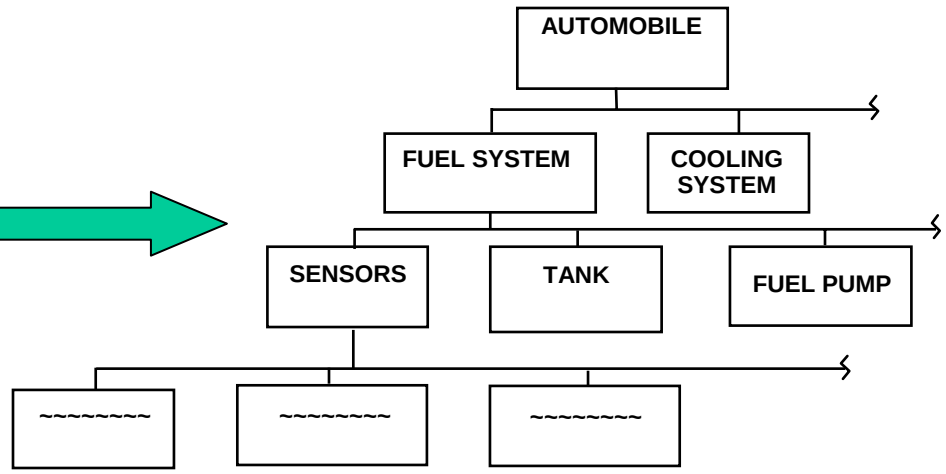
Organizing

ORGANIZATION
Guideline 1: Define the authorized work elements for the program. A Work Breakdown Structure (WBS), tailored for effective internal management control, is commonly used in this process.
Guideline 2: Identify the program organizational structure including the major subcontractors responsible for accomplishing the authorized work, and define the organizational elements in which work will be planned and controlled.
Guideline 3: Provide for the integration of the company's planning, scheduling, budgeting, work authorization and cost accumulation processes with each other, and as appropriate, the program work breakdown structure and the program organizational structure.
Guideline 4: Identify the company organization or function responsible for controlling overhead (indirect costs).
Guideline 5: Provide for integration of the program work breakdown structure and the program organizational structure in a manner that permits cost and schedule performance measurement by elements of either or both structures, as needed.

- The organizing processes drives the entire EVM framework.
- It defines the work and creates a logical structure for planning and control (WBS).
- It also defines the organization that performs the work (OBS).
- And assigns responsibilities and authorities (RAM).

Work Breakdown Structure Organizes The Work

1.0 Automobile
- 1.1 Fuel System
  - 1.1.1 Sensors
  - 1.1.2 Tank
  - 1.1.3 Fuel Pump
  - ⋮
  - 1.x.x Etcetera
- 1.2 Cooling System
- 1.3 Ignition System
- 1.4 Suspension
- ⋮
- 1.8 Electrical



The WBS should define the product or deliverable represented by the scope of work, not the budget, the organization, or the tasks.

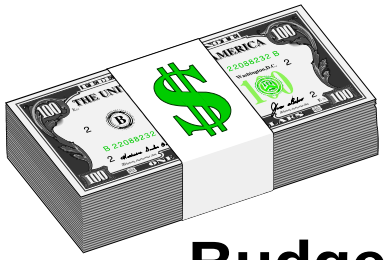
The completed WBS represents the project in terms of the hierarchy of the product and it's major components.

The project is described just as a manufacturer would document the bill of materials breakdown for a computer or automobile.

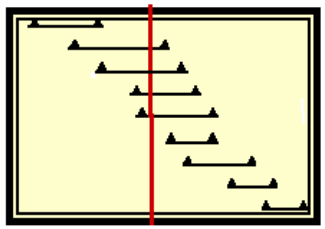
The WBS Dictionary Is A Key Element of the WBS

- The WBS contains a dictionary (WBS Dictionary)
  - Used to describe work scope associated with each element in the WBS structure
  - Is needed to ensure all work scope has been included in the schedule and the estimate.
- Especially important if the WBS is extensive and the content is *not* apparent
- Sample:
  - *WBS Element 1.3.3.4. - Systems Integration. This element is the effort to conduct the systems integration process including hardware, software, and communications.*

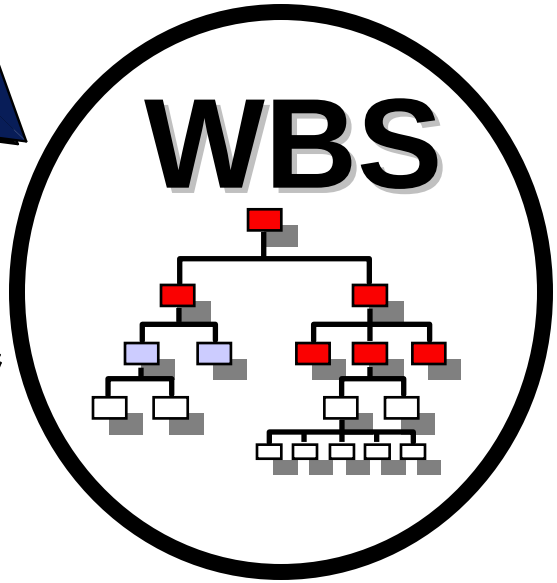
Work Breakdown Structure: The Key to Integration



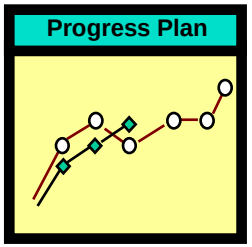
Budget



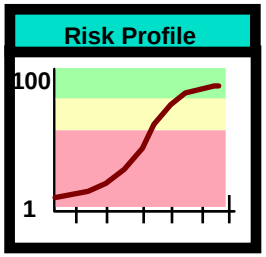
SCHEDULE



TECHNICAL PERFORMANCE



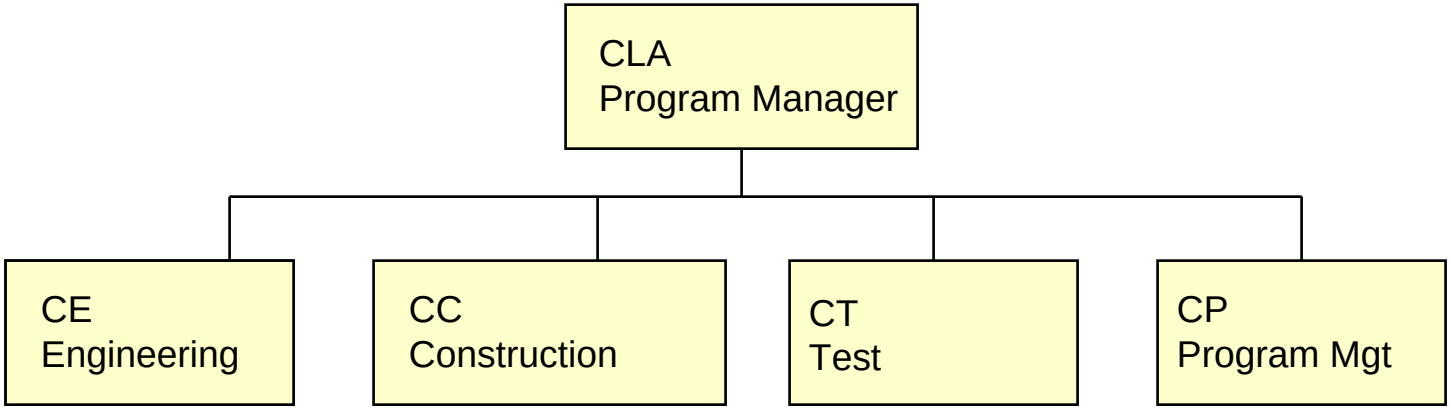
RISK



- WBS is the glue the providing the means for traceability, reconciliation, performance reporting and management
- WBS is the most critical element because it ties everything together and you will have to live it until the end of the program!

The Organization Breakdown Structure Organizes the Workers

This organization is called the "performing organization" because it is the organization accomplishing the work!



- Similar to the WBS, the OBS provides the means for controlling resources and assessing effectiveness.
- Poor performance could indicate resource estimates were inadequate or that the processes are inefficient.

The Responsibility Assignment Matrix Integrates the Work and the Organization Performing the Work

	Engineering	Construction	Test	Program Management
1.1 Fuel System				
1.2 Ignition				
1.4 Suspension				
1.7 Frame				
1.8 Electrical				

- The RAM assigns work and resources at lowest level (control account)
- It also establishes responsibility for WBS elements
  - Performing organization
  - Control Account Manager (CAM)
  - Includes responsibility for overhead

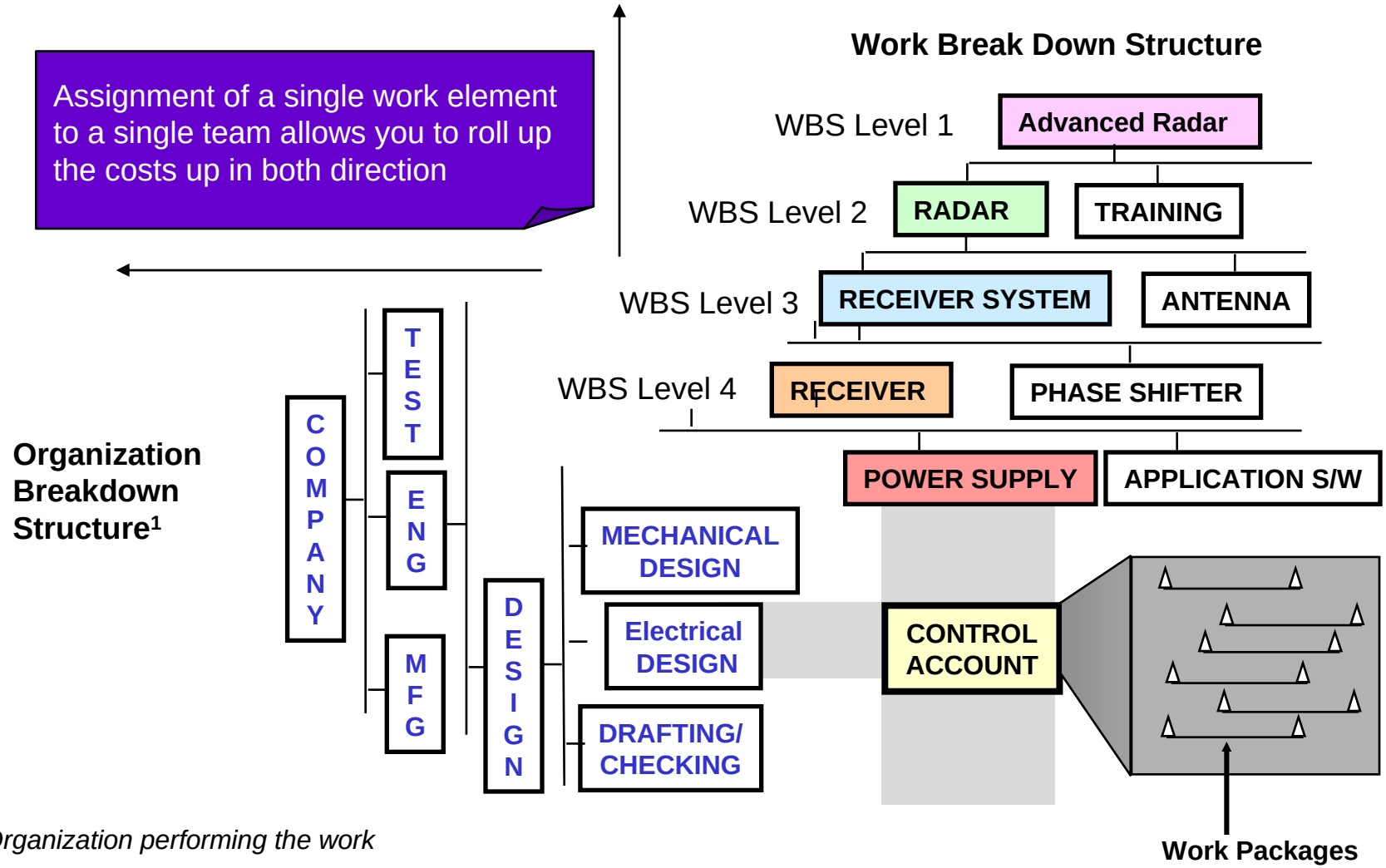
Budget Is Assigned To Control Accounts

	Engineering	Construction	Test	Program Management
1.1 Fuel System	5000	2000	2,000	1500
1.2 Ignition				1500
1.4 Suspension				
1.7 Frame				
1.8 Electrical	3500		2500	1500

- Budget (*not funds*) is allocated to each control account in accordance with the estimates
- No work can begin or be accomplished without budget!

Integration of OBS and WBS

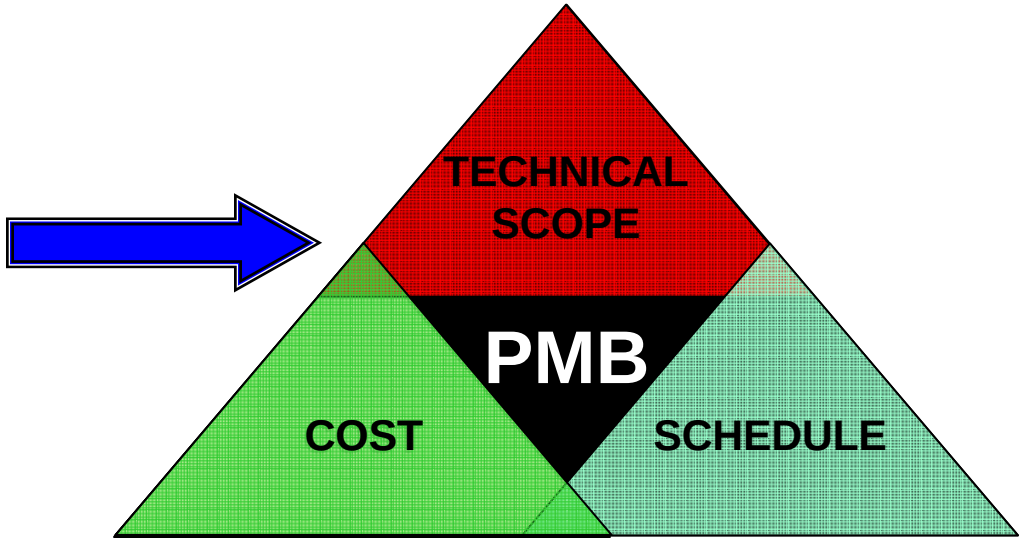
Assignment of a single work element to a single team allows you to roll up the costs up in both direction



[1]*Organization performing the work*

Control Account Manager

- CAMs have the authority and responsibility to:
  - Understand the baseline
  - Manage assigned effort
    - Technical
    - Schedule
    - Cost
  - Conduct variance analysis



When EVM is implemented in house within the government program office, the government will also have CAMs with similar responsibilities

Planning, Scheduling and Budgeting

PLANNING, SCHEDULING & BUDGETING
Guideline 6: Schedule the authorized work in a manner, which describes the sequence of work and identifies significant task interdependencies required to meet the requirements of the program.
Guideline 7: Identify physical products, milestones, technical performance goals, or other indicators that will be used to measure progress.
Guideline 8: Establish and maintain a time-phased budget baseline, at the control account level, against which program performance can be measured. Budget for far-term efforts may be held in higher-level accounts until an appropriate time for allocation at the control account level. Initial budgets established for performance measurement will be based on either internal management goals or the external customer negotiated target cost including estimates for authorized but undefinitized work. On government contracts, if an over target baseline is used for performance measurement reporting purposes, prior notification must be provided to the customer.
Guideline 9: Establish budgets for authorized work with identification of significant cost elements (labor, material, etc.) as needed for internal management and for control of subcontractors.

This next set of processes accomplishes a logical approach to planning

1. Sequence the work
2. Define interdependencies
3. Establish the required budgets for the work including overhead, reserve and other budget not direct attributable to the scope
4. Identify meaningful measures of progress
5. Define control the control accounts against which performance is measured

Planning, Scheduling and Budget Continued

Guideline 10: To the extent it is practical to identify the authorized work in discrete work packages, establish budgets for this work in terms of dollars, hours, or other measurable units. Where the entire control account is not subdivided into work packages, identify the far term effort in larger planning packages for budget and scheduling purposes.
Guideline 11: Provide that the sum of all work package budgets plus planning package budgets within a control account equals the control account budget.
Guideline 12: Identify and control level of effort activity by time-phased budgets established for this purpose. Only that effort which is unmeasurable or for which measurement is impractical may be classified as level of effort.
Guideline 13: Establish overhead budgets for each significant organizational component of the company for expenses, which will become indirect costs. Reflect in the program budgets, at the appropriate level, the amounts in overhead pools that are planned to be allocated to the program as indirect costs.
Guideline 14: Identify management reserves and undistributed budget.
Guideline 15: Provide that the program target cost goal is reconciled with the sum of all internal program budgets and management reserves.

Control Accounts

- Control Accounts are where the action is
  - Represents the work assigned to **one** responsible organizational element on **one** program work breakdown structure element (intersection of WBS and OBS)
  - Assigns work (scope) and resources at lowest level
  - Natural management point for planning and control
  - Performance measurement (Earned Value)

- Rules of Thumb
  - Integration of work, cost of the work, and schedule for the work
  - Homogeneity* of work
  - What is logical to manage every day
  - Examine: nature of the work, breakout of labor, span of control
  - Typically 6 - 18 months for discrete effort; level of effort can be longer

*resemblance in structure

So, what's in a Control Account?

SOW

1.3.4.1

Build radar

SCHEDULE

Dev

I&C

BUDGET

Labor	1,000 hrs
Labor $	75,000
Material $	25,000

CONTROL ACCOUNT PLAN

CAM name: _____ WBS: _____ Total Budget: _____

Work	$	$	$		
Work		$	$	$	
Work			$	$	$

Control Account Elements

Work Packages

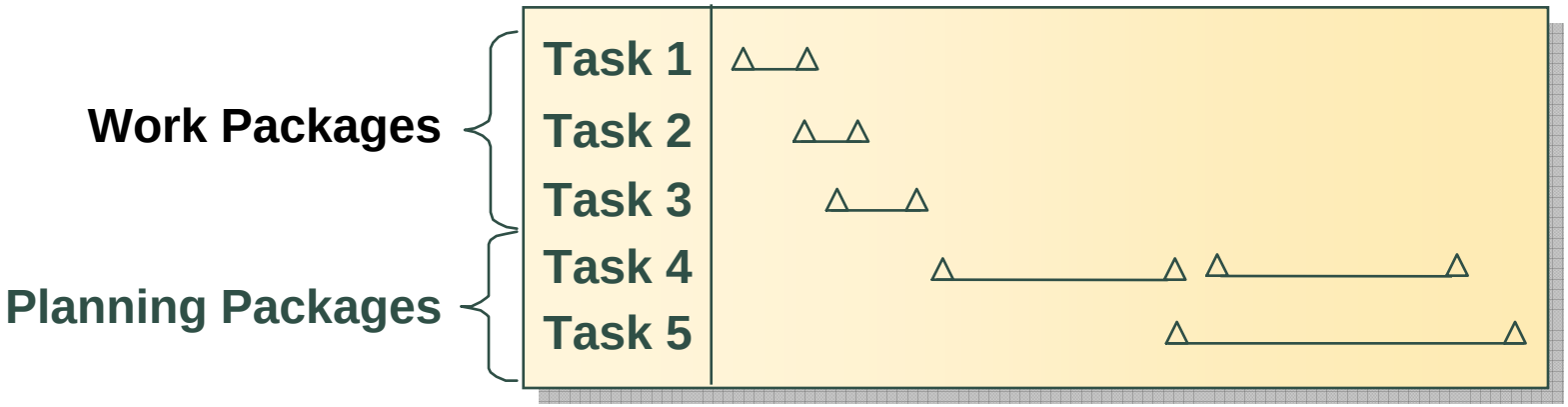
Detailed, short-span tasks, or material items, required to accomplish the CA objectives, typically in the near term

(resources)

Planning Packages

Future work that has not been planned in detail as work packages. They are always scheduled to occur in the future.

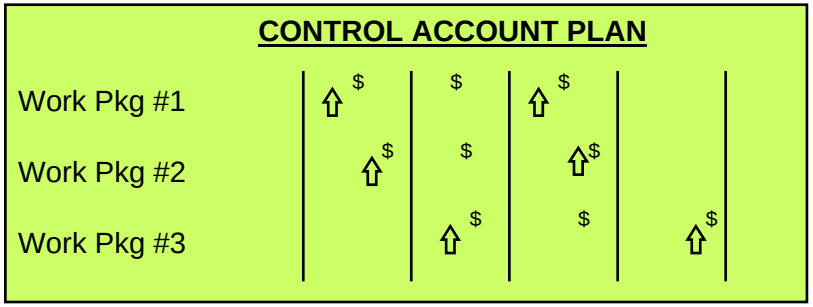
(budget)



Planning packages do not earn value because no work can be accomplished within a planning package!

Work Packages

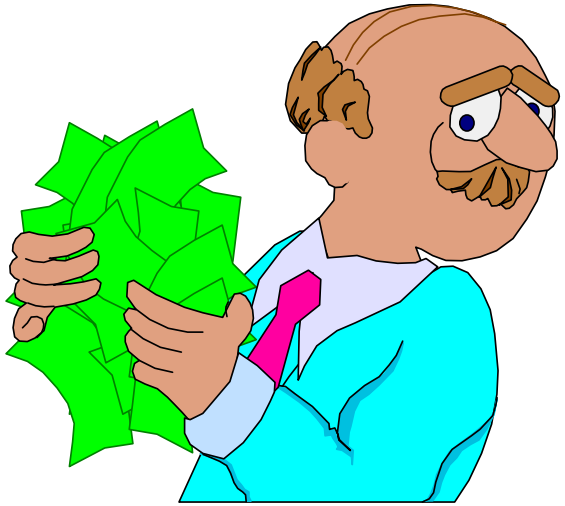
- **<u>Development of Control Account Plans</u>**
  - <u>Often</u> broken down into smaller work packages
- **<u>Work Packages</u>**
  - subset of control account
  - reasonably short in duration
  - single element of cost (e.g., labor)
  - single technique for earning value
  - aligned with detail schedules
  - has same characteristics as control account
    - scope of work
    - milestone completion criteria
    - single performing organization
    - start and end dates



Earned Value

Earned Value Is A Measure

- An *Objective* Measure of how much Work has been accomplished based on the planned value.....



What we got for what we Spent!

Understanding Earned Value

- Value is earned by completing work.
  - Task "earns" the allocated budget as work is completed
  - Value is earned even if the work is not paid for immediately
  - Can only occur for authorized budget, or work that is defined in the scope of the project (Performance Measurement Baseline)

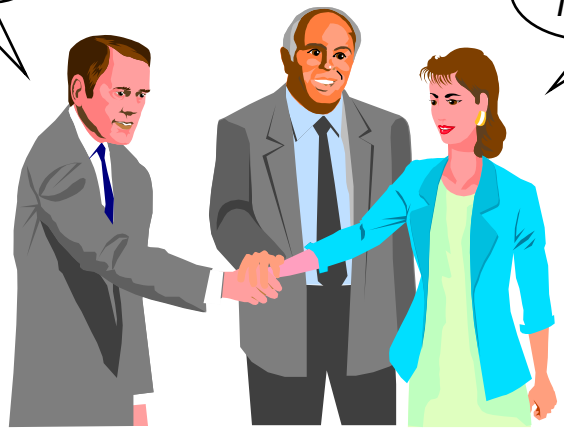
- How value is determined is based on the type of effort

- *Cannot change* the method once the task is planned and authorized

A Short Example

It's my pleasure to award you this contract for a new railroad track

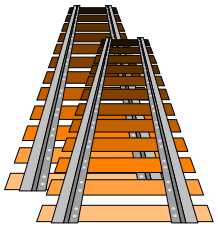
hmm...1 mile of track, 10 months to do it all....$20,000 budget....This is going to be tough!



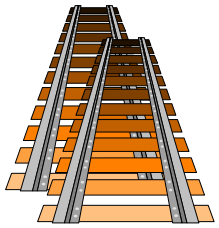
The Job

The Plan

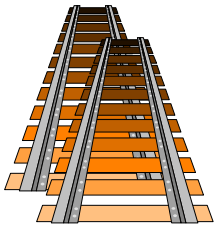
Budgeted Cost of Work Scheduled (BCWS) (Planned Value)



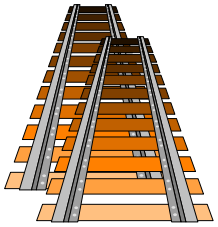
Month 1
PV = $2,000



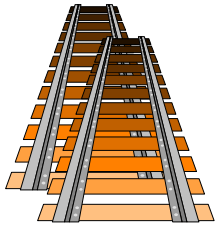
Month 2
PV = $2,000



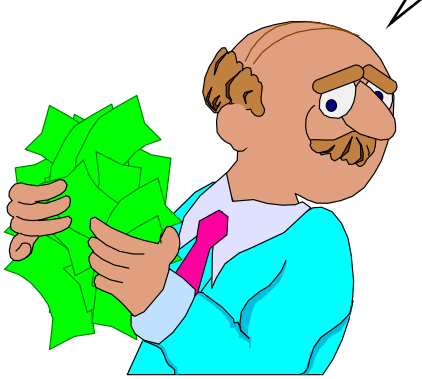
Month 3
PV = $ 2,000



Month 4
PV = $2,000



Month 5
PV = $2,000

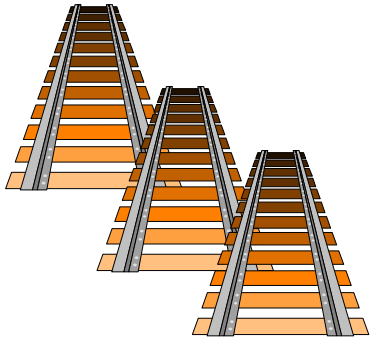


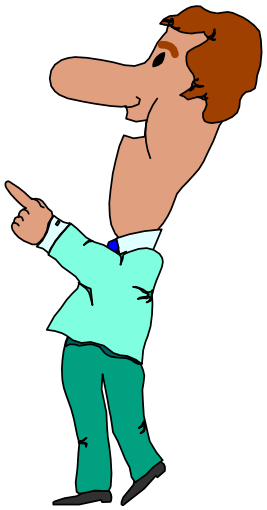
Total Budget = $20,000
to be spent over 10 months
I plan to lay 2 sections
of track each month at an
estimated cost of $1,000 each.
BCWS each month = $2,000

Each dollar of planned value represents a specific dollar of work scope

Budgeted Cost of Work Performed (BCWP) (Earned Value)

the EARNED VALUE concept

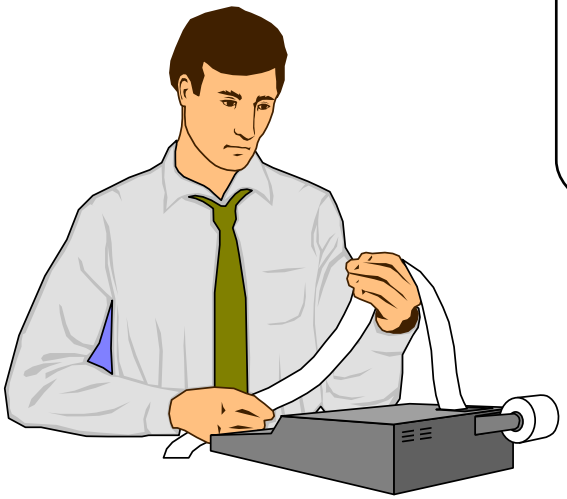




We're at the end of the fifth month, but only 3 sections of track are complete. The **value** of work performed = $3,000

You earn value the same way as it was budgeted in the baseline

Actual Cost of Work Performed (ACWP)

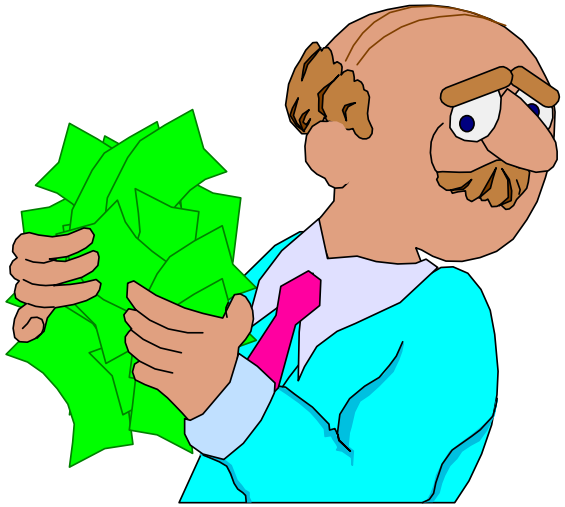


Labor came to $3,900, and materials cost $2,100. Those 3 sections of track cost $6,000!

actual expenditures vs.. budget

After 5 Months…..

- What we planned and how much we budgeted for it
  - 10 sections of track for $10,000
- What we got and what it cost us
  - 3 sections of track for $6000



Did we get what we wanted for what we spent?

Earned Value Techniques

A predetermined amount of budget, that is claimed, or earned, when the corresponding work is accomplished. The budget value is earned in one of the following ways:

- ☑ 0/100
- ☑ X/Y Percent
  - 25/75
  - 40/60
  - 50/50
- ☑ Equivalent Units
- ☑ Weighted Milestones
- ☑ Weighted Milestones using Percent Complete
- ☑ % Complete
  - Subjective Estimate
  - Objective Indicators
- ☑ Apportioned Effort
- ☑ Level of Effort

Earned Value Techniques - Discrete

- Used where there are specific deliverables (products, events, data) that can be discretely measured

- Fixed Formula method for determining progress for work packages that span a short period of time.
  - Usually for short term work
  - 0/100 - Nothing is earned when activity starts but 100% of budget is earned when completed
  - 50/50 - 50% is earned when activity starts and the balance is earned on completion
  - 25/75 - 25% is earned when activity starts and the balance is earned on completion
  - i.e. Flight Check – 0% / 100%

- Weighted Milestones. Used for significant milestones (start, finish, design reviews, et al). Can also be defined by completed actions and product delivery.
  - Long term work packages with long term durations
  - Budget value assigned to each milestone. Upon completion budget is earned.
  - i.e. Site Construction:
    - Foundation complete – 15%
    - Beneficial Occupancy – 60%
    - Building complete – 75%
    - Installation Complete – 100%

Earned Value Techniques - Discrete

- Weighted Milestone with Percent Complete. Used where work is broken down into percentage of completion (subjective)
  - Budget value is assigned to each milestone, and is earned based on the percent of work completed
  - Requires identification of the criteria used to conduct the assessment.
  - i.e. System Design, Preliminary Design, Final Design

- Units complete. Units complete can be measured by direct unit count, equivalent unit count or standard resources (hours) per unit.
  - Budget value assigned for completed units.
  - Can be broken down for partial completion if necessary
  - Units must be identical or similar and they must have the same budget value.
  - i.e. ASR-11 Radar delivery

Earned Value Techniques – Apportioned & Level of Effort

- Used for work packages that cannot be discretely measured by themselves
  - Directly related to another discrete task that can be measured and that relationship can be defined.
  - i.e. Quality Assurance
- Level of Effort. Monthly budget value is earned with elapsed time and is always equal to the monthly planned amount.
  - BCWS always equal to the BCWP.
  - Used for work and accounts that are more time related than task oriented
  - No specific end product
  - i.e. Program and Project Management, Second Level Engineering

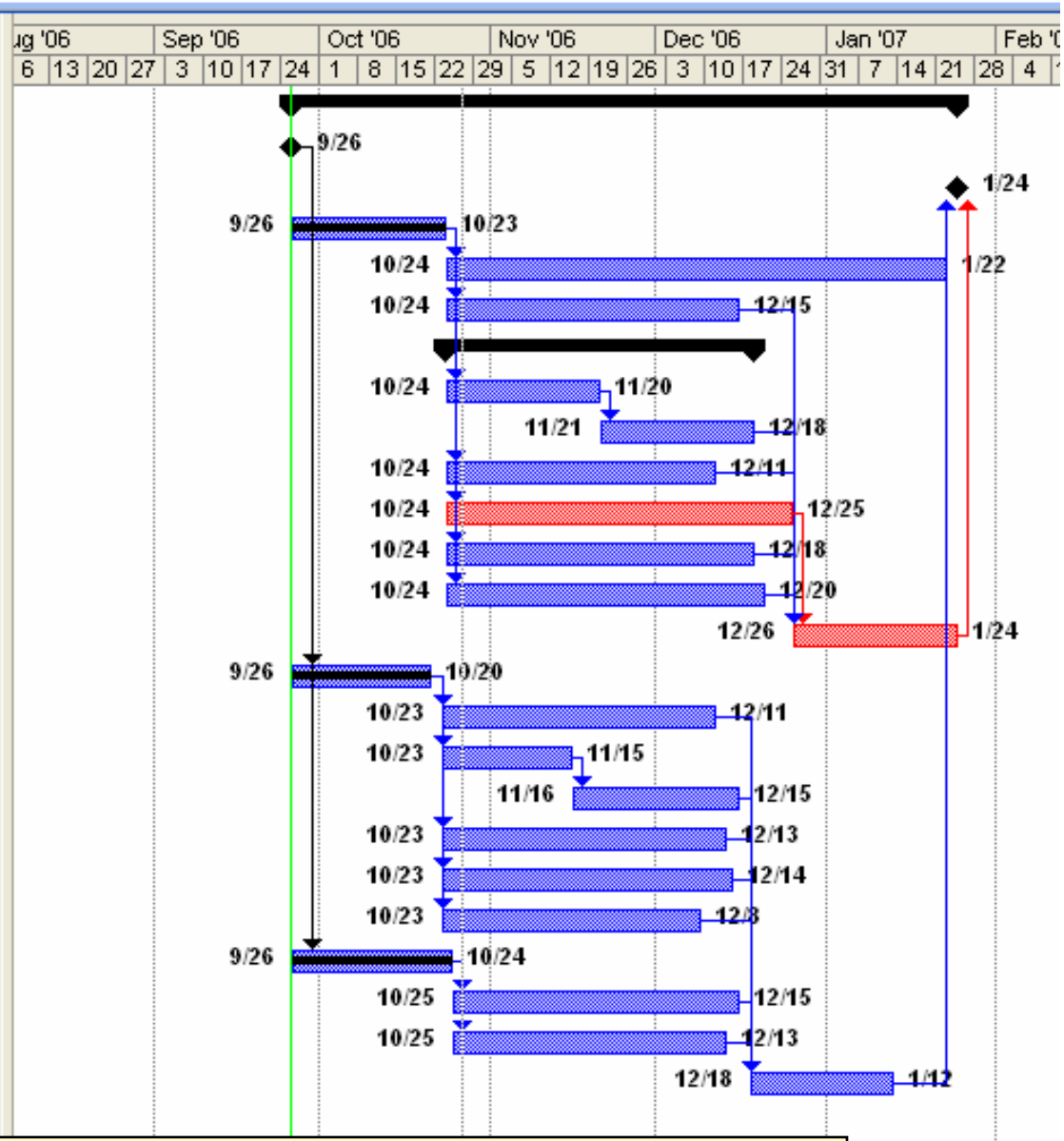
Scheduling

- Scheduling begins with defining the necessary outcomes
  - Deliverables
  - Milestones (events)
- Deliverables are products
  - Documents
  - Demonstration
  - Hardware/Software
  - Defined outcomes
  - Every task in the schedule needs to have a defined outcome
- Milestones
  - Completion of an activity or deliverable (must be measurable).
  - Activities must have definite a start and stop.
  - A point in time not a time period like an activity.

Tasks | Resources | Track | Report

1.2

	WBS	Task Name	Focus Dur	Total Slack
1	**1**	**Correlated Risk Schedule**	**87 days**	**0 days**
2	1.1	Project Start	0 days	0 days
3	1.2	Project End	0 days	0 days
4	1.3.1	1.3.1	20 days	0 days
5	1.3.11	1.3.11	65 days	2 days
6	1.3.10	1.3.10	39 days	6 days
7	**1.3.12.**	**1.3.12.1**	**40 days**	**5 days**
8	1.3.12.	a	20 days	5 days
9	1.3.12.	b	20 days	5 days
10	1.3.12.	1.3.12.2	35 days	10 days
11	1.3.13.	1.3.13.1	45 days	0 days
12	1.3.13.	1.3.13.2	40 days	5 days
13	1.3.13.	1.3.13.3	42 days	3 days
14	1.3.13.	1.3.13.4	22 days	0 days
15	1.3.16.	1.3.16.1	19 days	0 days
16	1.3.15.	1.3.15.1	36 days	12 days
17	1.3.17.	1.3.17.2	18 days	8 days
18	1.3.17.	1.3.17.4	22 days	8 days
19	1.3.17.	1.3.17.1	38 days	10 days
20	1.3.17.	1.3.17.3	39 days	9 days
21	1.3.17.	1.3.17.5	35 days	13 days
22	1.3.2.1	1.3.2.1	21 days	0 days
23	1.3.2.2	1.3.2.2	38 days	8 days
24	1.3.2.3	1.3.2.3	36 days	10 days
25	1.3.2.4	1.3.2.4	20 days	8 days

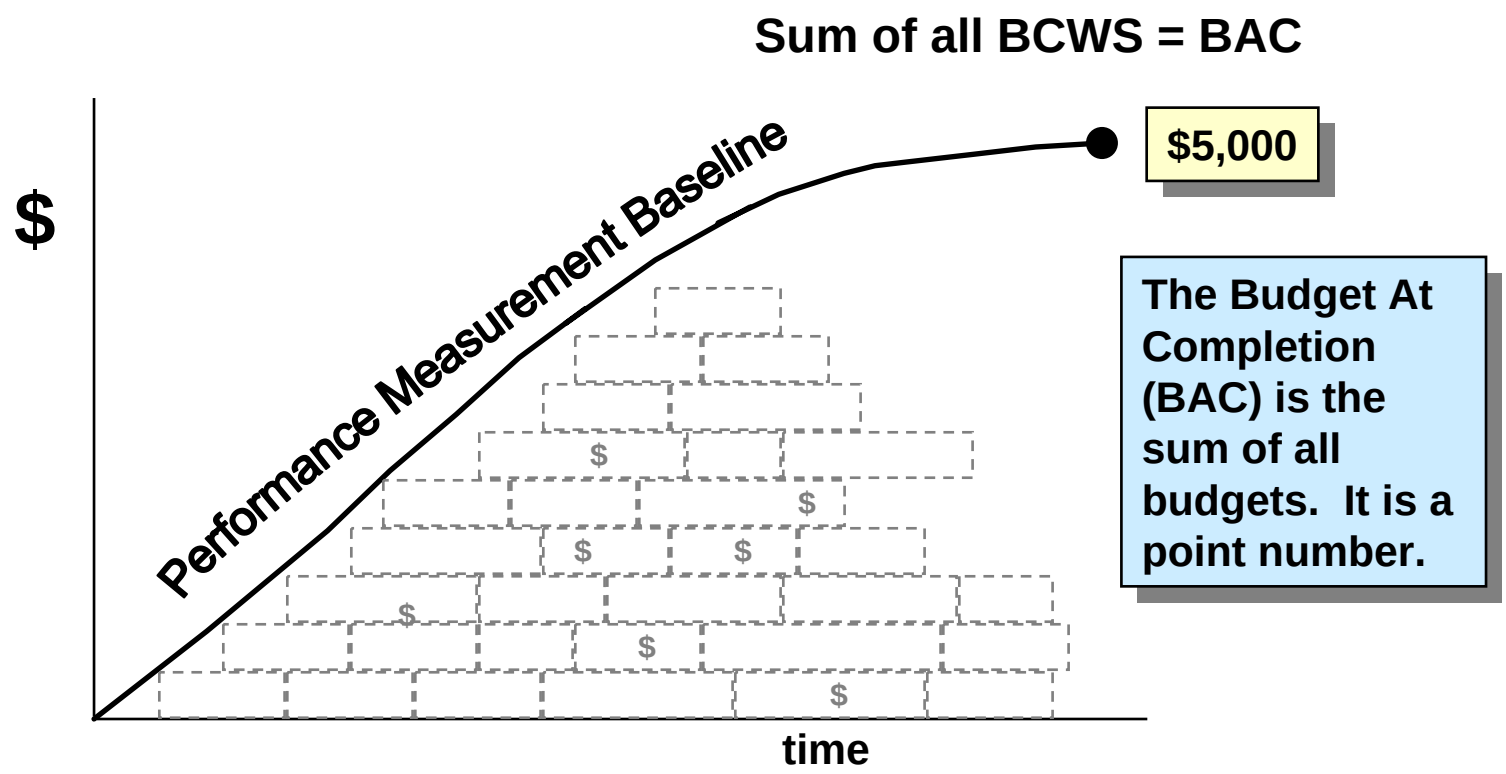


The result is a detailed schedule with tasks in the proper sequence and resources loaded that can be used to manage progress and performance

The Performance Measurement Baseline (PMB)

- The scheduling process results in a monthly time-phased budget to project completion which is the result of
  - Work packages (resource-loaded)
  - Planning packages (budget-loaded)
- The PMB is **NOT** the Performance Baseline (APB)(JRC baseline) and does **NOT** equal the total cost of the project/investment
  - Why? Because the PMB only consists of work scope
  - Items such as Profit, Fee, Management Reserve and anything else that is not work scope is not part of the PMB
- The PMB is the Earned Value measurement point
  - Why? Because progress and performance need to be measured against the required scope; NOT against budget dollars

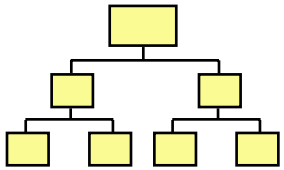
The PMB is a Curve



The PMB is a curve that that results from the cumulative BCWS added over time when all work has been time phased (Cumulative BCWS = BAC)

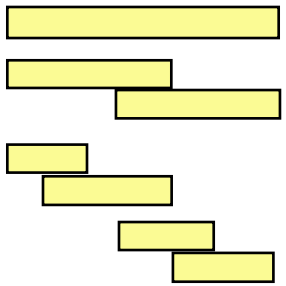
3 Step Process for development of the Performance Measurement Baseline

1. Define The Work



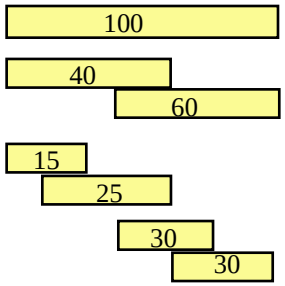
- **Develop WBS**
- **Extend WBS to Control Account/Work Package**

2. Schedule The Work

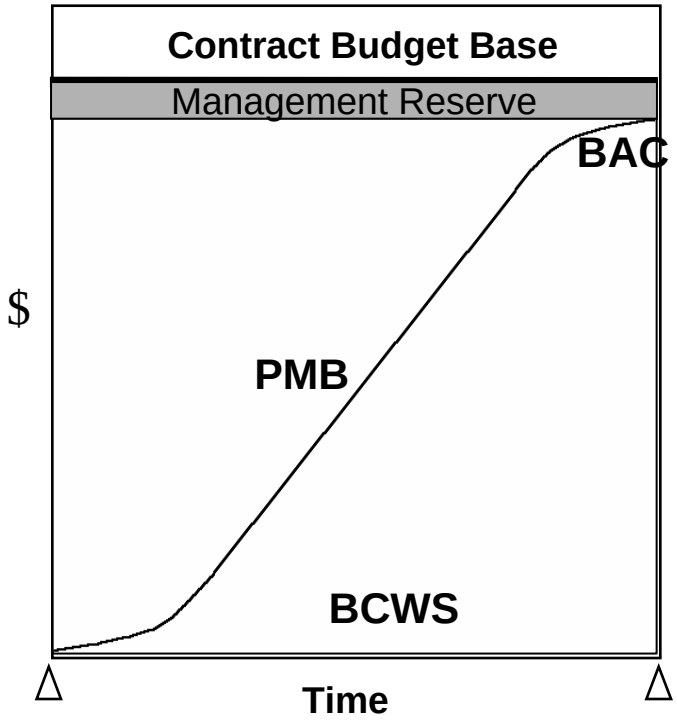


- **Arrange Work Packages in sequence**
- **Time phase the schedule**

3. Allocate Budgets

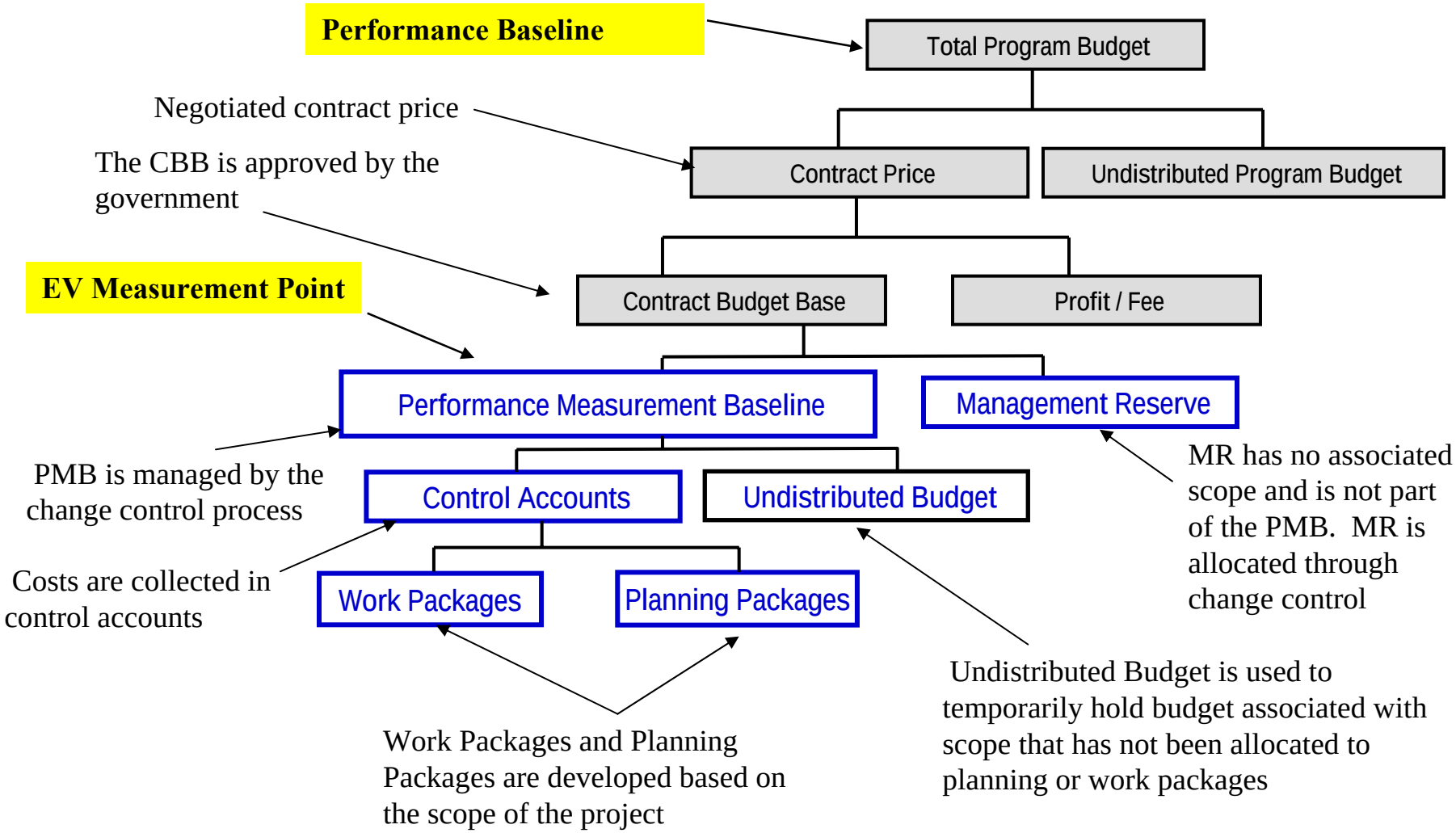


- **Budget Work Packages**
- **Classify the Work and Select An EV Method**
- **Aggregate Cum BCWS**



- PMB- Time-phased budget plan against which performance is measured
- Integrates technical scope, cost and schedule

Budget and PMB Relationships



More Acronyms!

Undistributed Budget (UB) Budget associated with specific work scope or contract changes that have not been assigned to a control account or planning package. For short term holds between accounting periods.

Performance Measurement Baseline (PMB) The total time-phased budget plan against which program performance is measured. It is the schedule for expenditure of the resources allocated to accomplish program scope and schedule objectives, and is formed by the budgets assigned to control accounts. Management Reserve is not included in the baseline as it is not yet designated for specific scope.

Management Reserve (MR) An amount of the total budget withheld for management control purposes. Is not part of the PMB and there is no performance measurement for MR, because it has no work scope. It is used for growth in work scope, rate changes and other unknowns (unforeseen changes that are within scope of the project). Not used to offset overruns.

Contract Budget Base (CBB) Total budget allocated to the scope of work (does not include profit or fee)

Accounting Considerations

ACCOUNTING CONSIDERATIONS
Guideline 16: Record direct costs in a manner consistent with the budgets in a formal system controlled by the general books of account.
Guideline 17: Summarize direct costs from control accounts into the work breakdown structure without allocation of a single control account to two or more work breakdown structure elements.
Guideline 18: Summarize direct costs from the control accounts into the contractor's organizational elements without allocation of a single control account to two or more organizational elements.
Guideline 19: Record all indirect costs, which will be allocated to the contract.
Guideline 20: Identify unit costs, equivalent unit costs, or lot costs when needed.
Guideline 21: For EVMS, the material accounting system will provide for accurate cost accumulation in a consistent manner using recognized techniques; cost performance measurement at the most suitable point; full accountability of all material purchased.

- Integration with the accounting system used by the performing organization provides accurate information on costs.
- The purpose of the accounting process in EVM is not to perform financial accounting but to obtain information for performance management purposes.
- Currency and accuracy are equally important. Old and accurate information is less useful then current less accurate information. Estimated actuals should be used when the timeliness is an issue.

Key Points About Accounting

- Costs should be collected and accumulated at the Control Account point.
  - For significant lags in availability of cost data (outlays), estimated costs can be used in the short term

Require a balance between accuracy and currency. If you wait for precise information, the information will be useless to you as a manager!

  - Reconciliation must be accomplished periodically (should be quarterly)

- The term "costs" or "actual costs" is intended to be the performing organization's costs (paid by the customer) including direct and indirect (overhead)
  - Direct, Indirect (overhead)

- When these costs are not identifiable/reportable (fixed-price situations), costs/actual costs = customer's costs (which is paid by the customer)
  - Therefore, actual costs = the costs paid by the customer (sometimes called price in fixed-price contracts)

Analysis and Management

ANALYSIS & MANAGEMENT
Guideline 22: At least on a monthly basis, generate the following information at the control account and other levels as necessary for management control using actual cost data from, or reconcilable with, the accounting system: (1) Comparison of the amount of planned budget and the amount of budget earned for work accomplished. This comparison provides the schedule variance. (2) Comparison of the amount of the budget earned the actual (applied where appropriate) direct costs for the same work. This comparison provides the cost variance.
Guideline 23: Identify, at least monthly, the significant differences between both planned and actual schedule performance and planned and actual cost performance, and provide the reasons for the variances in the detail needed by program management.
Guideline 24: Identify budgeted and applied (or actual) Indirect costs at the level and frequency needed by management for effective control, along with the reasons for any significant variances.

- These processes are often mistaken as the crux of EVM.
- Earned Value formulas and graphs are the output of these processes.
- But generation of the reports is just a small part of these processes.
- Analyzing the information and taking action (management) are the key elements in this set of processes.

Analysis and Management Continued

Guideline 25: Summarize the data elements and associated variances through the program organization and/or work breakdown structure to support management needs and any customer reporting specified in the contract.
Guideline 26: Implement managerial actions taken as the result of earned value information.
Guideline 27: Develop revised estimates of cost at completion based on performance to date, commitment values for material, and estimates of future conditions. Compare this information with the performance measurement baseline to identify variances at completion important to company management and any applicable customer reporting requirements including statements of funding requirements.

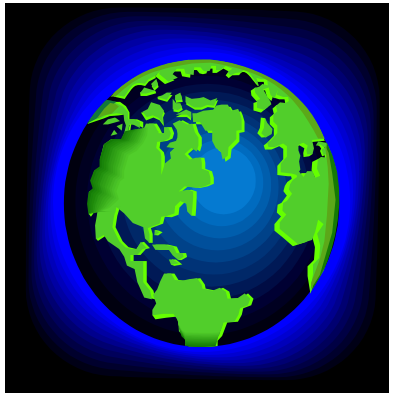
Note that Guideline 26 is a real requirement contained in the standard. You must use the information to manage. No action means no system!

In A Perfect World…

- The work we planned to do = work we accomplished = at the cost we planned

  BCWS = BCWP = ACWP

- Since we don't live in a perfect world, we will have a deviation from the plan referred to as variances
- *Variances are normal* because both perfect planning and perfect execution are impossible
  - Cost variance = BCWP - ACWP
    - + (less cost than planned is favorable)
    - - (more cost than planned is unfavorable)
  - Schedule variance = BCWP - BCWS
    - + (Earning more value than the plan is favorable)
    - - (Earning less value than the plan is unfavorable)

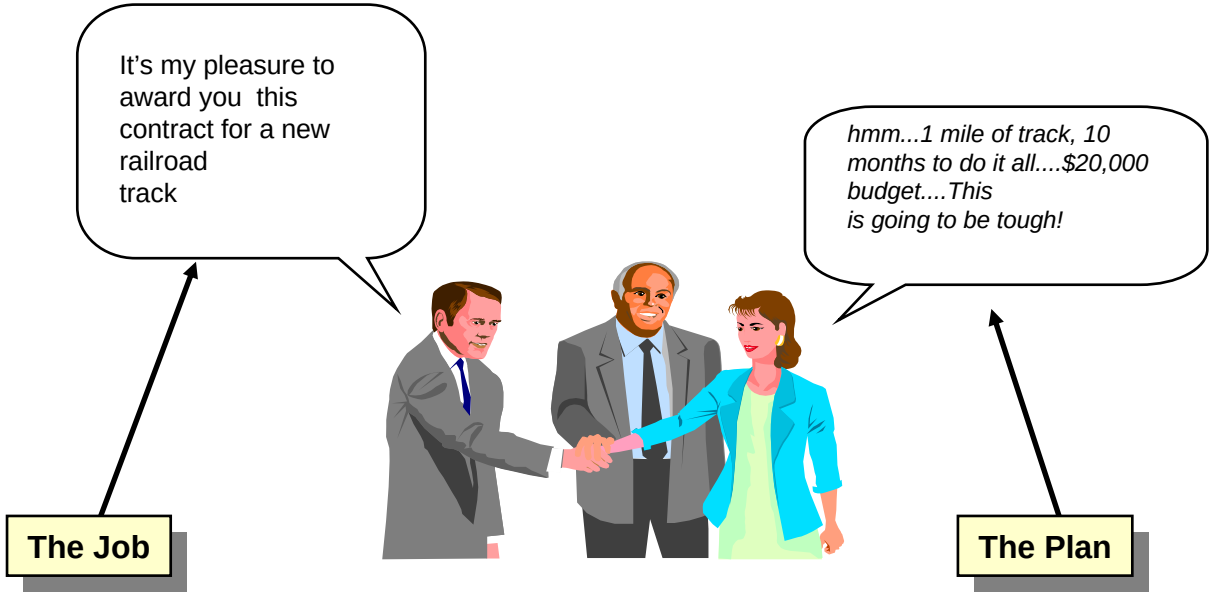


Note: Excessive positive variances are not necessarily good! May be poor estimates, incorrect EV techniques, padding, etc. Don't be fooled by data that says things are rosy!

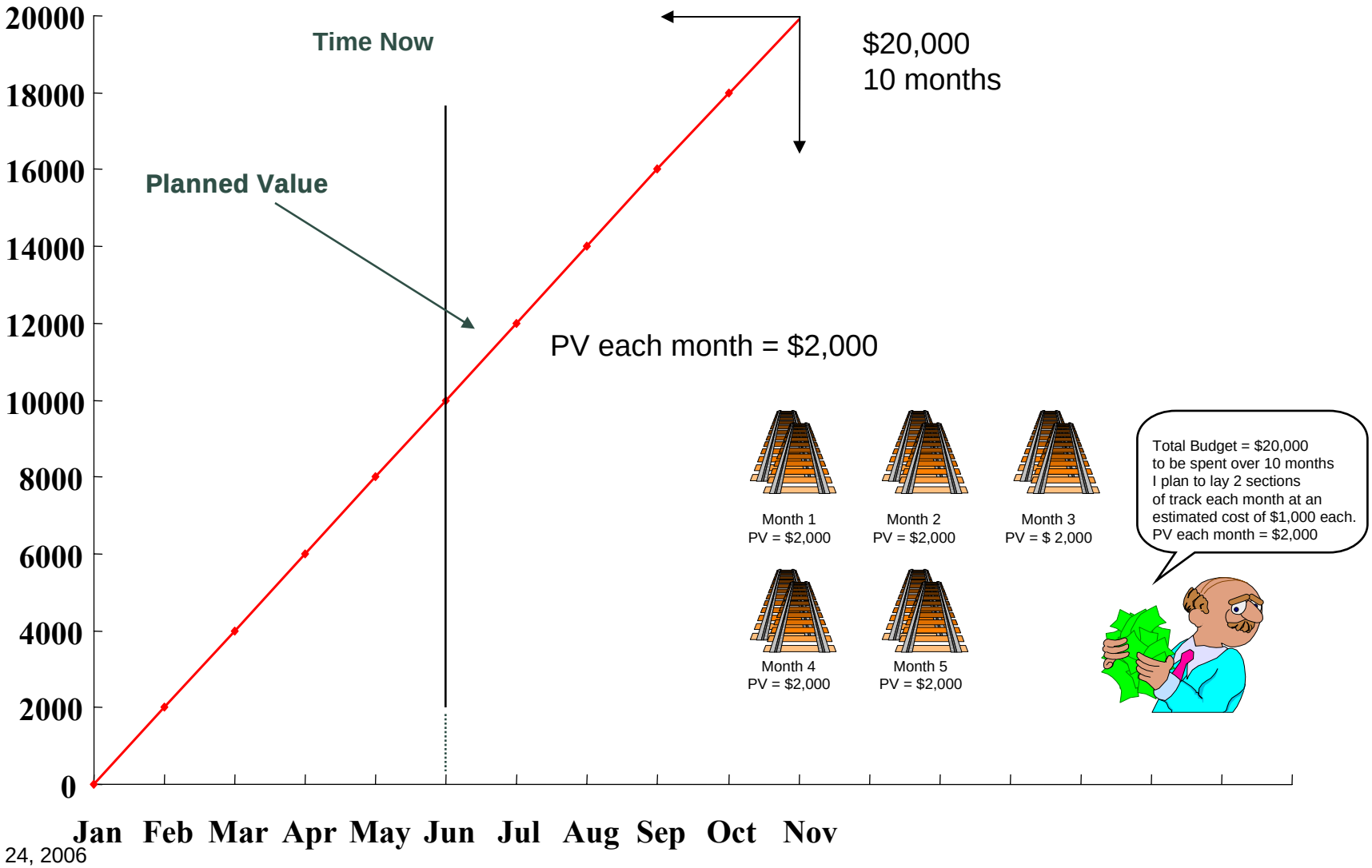
Earned Value Basic Performance Questions & Answers

Question	Answer	Acronym
How much work should be done?	Budgeted Cost for Work Scheduled	BCWS = PV
How much work is done?	Budgeted Cost for Work Performed	BCWP = EV
How much did the work cost?	Actual Cost of Work Performed	ACWP =AC
What was the total job supposed to cost?	Budget at Completion	BAC
What do we now expect the total job to cost?	Estimate At Completion	EAC

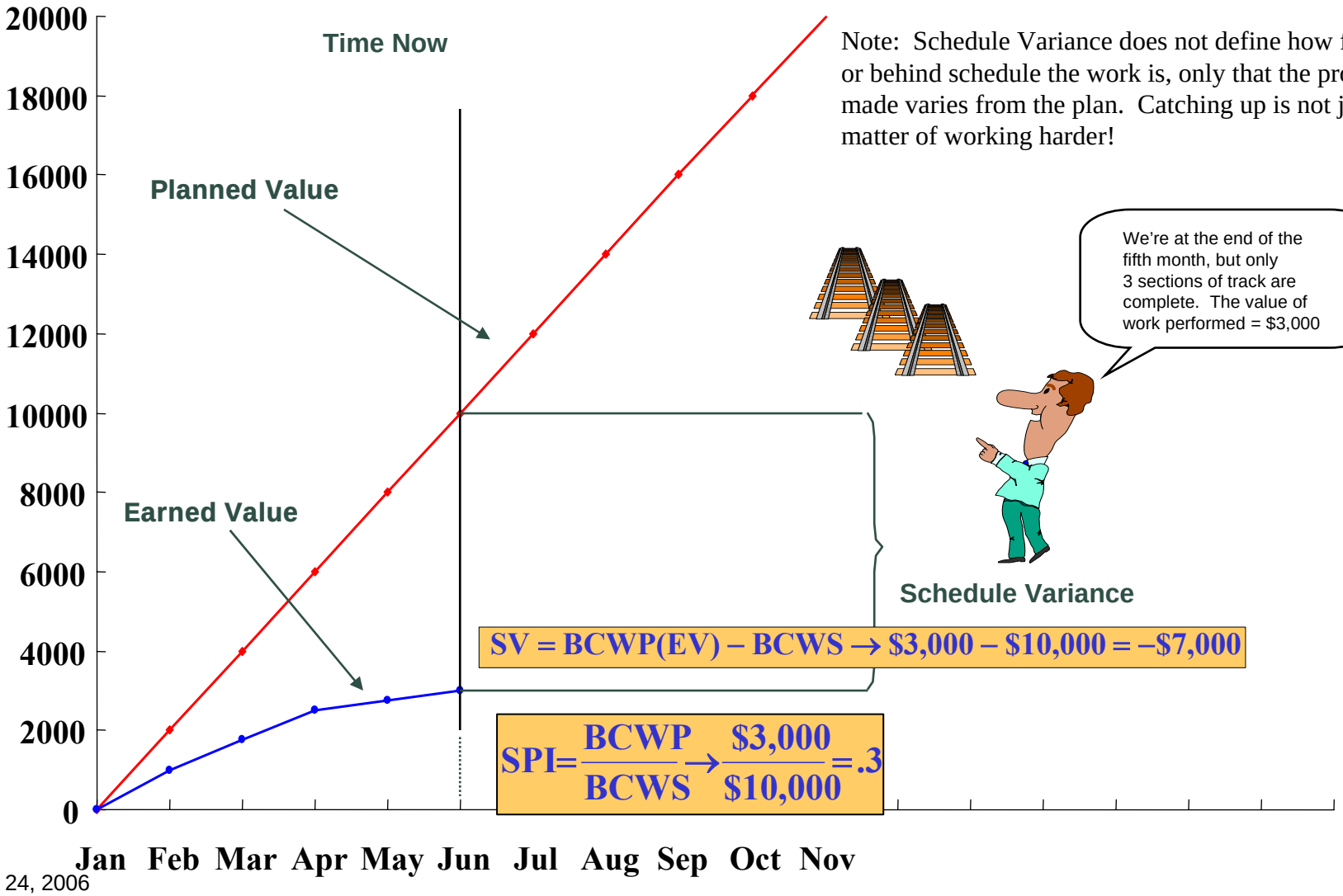
An Earned Value Example



The Plan



Measuring Schedule Progress



Note: Schedule Variance does not define how far ahead or behind schedule the work is, only that the progress made varies from the plan. Catching up is not just a matter of working harder!

$$SV = BCWP(EV) - BCWS \rightarrow \$3{,}000 - \$10{,}000 = -\$7{,}000$$

$$SPI = \frac{BCWP}{BCWS} \rightarrow \frac{\$3{,}000}{\$10{,}000} = .3$$

Schedule Variance

BCWS — of the work I scheduled to have done, how much did I budget for it to cost?

BCWP — of the work I actually performed, how much of that budget did I earn?

SCHEDULE VARIANCE is the difference between work scheduled and work performed (expressed in terms of budget)

formula: **SV $ = BCWP - BCWS**

example: SV = BCWP - BCWS = $3,000 - $10,000
SV= -$7,000 (negative = behind schedule)

A Key Point About Schedule Variance

- At the **end** of the project, when all work has been completed:
- Formal schedule will reflect whether milestones were achieved on time

SCHEDULE VARIANCE is the difference between work scheduled and work performed (expressed in terms of budget)

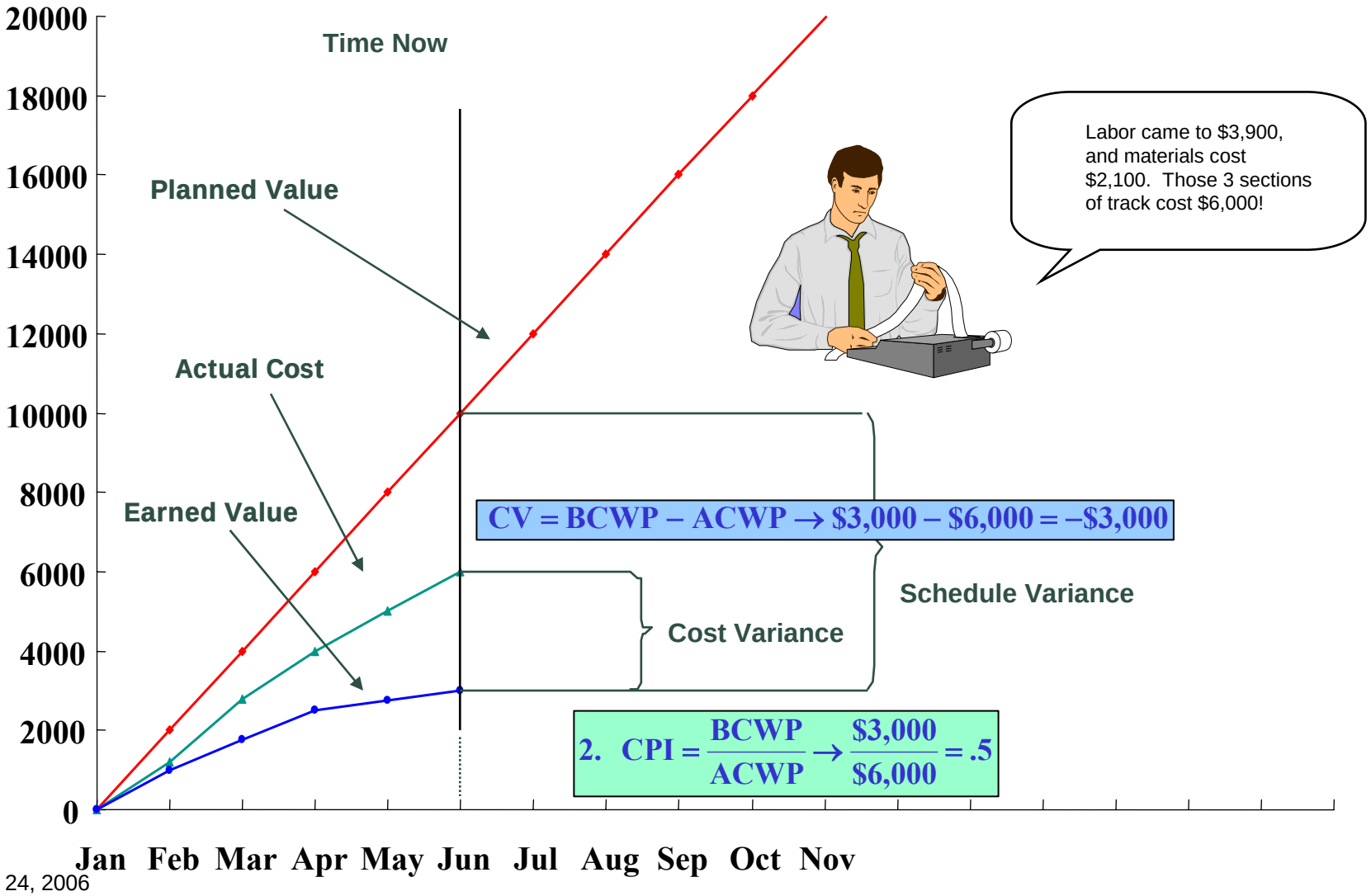
formula: **SV $ = BCWP - BCWS**

example: SV = BCWP - BCWS = $20,000 - $20,000
SV= 0

I may have finished late, but I did finish all the work. The schedule will reflect the delay, but the schedule variance will be zero.

Note: This is not the case with cost variance! The Cost Variance will remain at project complete.

Measuring The Cost Performance



Cost Variance

BCWP

of the work I actually performed, how much did I budget for it to cost?

ACWP

of the work I performed, how much did it actually cost?

COST VARIANCE is the difference between budgeted cost and actual cost

formula: **CV $ = BCWP - ACWP**

example: CV = BCWP - ACWP = $3,000 - $6,000
CV= -$6,000 (negative = cost overrun)

Variance at Completion (VAC)

BAC — what the **total** job is was budgeted to cost

EAC — what the **total** job is estimated to cost

VARIANCE AT COMPLETION is the difference between what the total job was budgeted to cost and what the total job is now estimated to cost.

FORMULA: VAC = BAC – EAC, where EAC= BAC/PF*

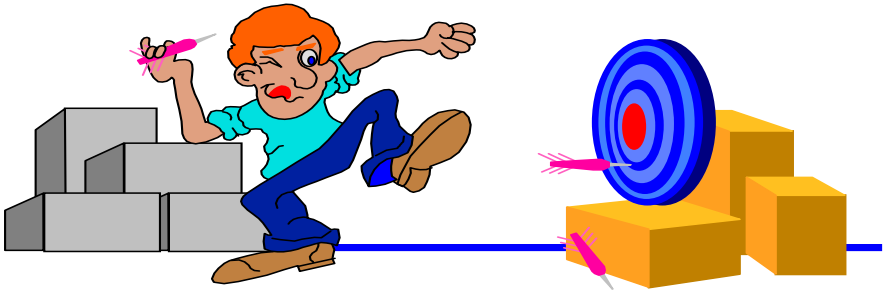
Example: EAC = $20000/.5 = $40,000
VAC = $20,000 - $40,000
VAC = - $20,000 (negative = overrun)

*There are also other formulas for calculating EAC

What will be the final cost? (Estimate At Completion)

- Actual cost to date + estimated cost of work remaining
- Consider the following in EAC generation
  - Performance to date
  - Impact of approved corrective action plans
  - Known/anticipated downstream problems
  - Best estimate of the cost to complete remaining work

ACWP + ETC = EAC



Common EAC Formulae

EAC

$$= \frac{BAC}{CPI}$$

$$= ACWP_{cum} + \frac{\text{Budgeted Cost of Work Remaining}}{CPI_3}$$

$$= ACWP_{cum} + \frac{\text{Budgeted Cost of Work Remaining}}{.8(CPI) + .2(SPI)}$$

$$= ACWP_{cum} + \frac{\text{Budgeted Cost of Work Remaining}}{CPI * SPI}$$

Other Methods

=

- "Bottoms Up" or formal EAC
- Average of statistical formulae
- Optimistic, Pessimistic, Most probable
- Schedule and cost risk analysis for remaining work

What does the data tells us about the project?

Are we on schedule?
Are we on cost?
What are the significant variances?
Why do we have variances?
Who is responsible?
What is the trend to date?

When will we finish?
What will it cost at the end?
How can we change the trend?

We analyze performance to help us control the future!

Using Indices To Predict The Future

- CPI and SPI are efficiency measures. Past efficiency is indicative of future performance.
- Use the current CPI to determine the needed efficiency to complete the project within budget. If the current CPI is:

$$\frac{\text{BCWP}}{\text{ACWP}} = \frac{\text{EARNED VALUE}}{\text{ACTUAL COST}} = \frac{\$3000}{\$6000} = .5$$

- Then the efficiency needed to finish within budget is:

$$\frac{\text{BAC-BCWP}}{\text{BAC-ACWP}} = \frac{\text{WORK REMAINING}}{\text{BUDGET REMAINING}} = \frac{\$17000}{\$14000} = 1.21$$

- Over 800 military programs show that **no** program has ever improved performance better than the following EAC calculation

$$\mathbf{EAC} = \frac{\mathbf{BAC}}{\mathbf{CPI}}$$ at 15% complete point in program

Budget Execution Status

$$\% \text{ Spent} = \frac{\text{ACWP(cum)}}{\text{BAC}} \times 100\%$$

$$\% \text{ Complete} = \frac{\text{BCWP(cum)}}{\text{BAC}} \times 100\%$$

Comparing % complete to % spent provides an indication of whether you will run out of budget before you run out of project.

Compare

% Spent vs.. % Complete

Example: 60% spent vs.. 50% complete

Variance Analyses

- Must address significant variances
- Separate discussion of cost and schedule variances
- Clear description of reason for variance
- Quantity variances (e.g., price vs.. usage)
- Be specific, not general
- Include corrective action
- Technical, schedule, and cost impacts
- Impact to estimate at completion
- Should be written by the individual controlling the work (CAM)!

What Are Significant Variances?

- Percentage variance (>10%)
- Dollar variance (>$100,000 at the control account level)
- Item is on the critical path
- Element has considerable risk
- Impact to other elements
- Top 10, the critical few.
- Contractor defined
- Agency defined

Problem Indicators

- Zero variances
- Disappearing variances
- Negative trends
- Re-baselining/replanning trend
- A cost increase generally follows a schedule variance
- Positive LOE variances
- Actual cost greater than Latest Revised Estimates
- BCWP increases with no increase in ACWP

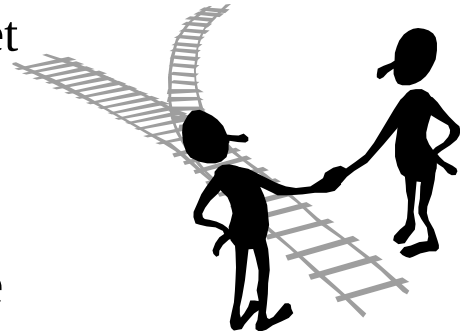
Revisions and Data Maintenance

REVISIONS & DATA MANAGEMENT
Guideline 28: Incorporate authorized changes in a timely manner, recording the effects of such changes in budgets and schedules. In the directed effort prior to negotiation of a change, base such revisions on the amount estimated and budgeted to the program organizations.
Guideline 29: Reconcile current budgets to prior budgets in terms of changes to the authorized work and internal re-planning in the detail needed by management for effective control.
Guideline 30: Control retroactive changes to records pertaining to work performed that would change previously reported amounts for actual costs, earned value, or budgets. Adjustments should be made only for correction of errors, routine accounting adjustments, effects of customer or management directed changes, or to improve the baseline integrity and accuracy of performance measurement data.
Guideline 31: Prevent revisions to the program budget except for authorized changes.
Guideline 32: Document changes to the performance measurement baseline.

- Maintaining the integrity of the baseline is accomplished through change control for authority to make changes and discipline to control retroactive change
- Controlling the baseline ensures accurate and reliable information
- All changes must be documented!

Authorizing the Work and Controlling Change

- Can only charge to open work packages
  - The EVM system must define the process
- Performing Organization maintains baseline log which tracks:
  - Distribution of budget from Undistributed Budget (UB) to control accounts
  - Distribution of Management Reserve (MR)
  - Addition of authorized work
- Changes incorporated in disciplined manner
  - Cannot start work without authorization or budget
- Baseline changes must be controlled
  - Internal replanning
  - Over Target Baseline, Over Target Schedule



Some Rules of the Road

- Cannot move budget without moving working and vice versa!
- Cannot use management reserve to cover overruns
- May replan open work packages (but carefully and infrequently)
  - Must retain historical performance information
- Cannot change budget or costs for completed work, except to fix errors.

Assessment of EVMS
Real program example

Results of CAM interviews and artifact review

		ORGANIZING	SCHEDULING	WORK/BUDGET AUTHORIZATION	ACCOUNTING	INDIRECT MANAGEMENT	MANAGERIAL ANALYSIS	CHANGE INCORPORATION	MATERIAL MANAGEMENT	SUBCO
ORGANIZATION										
1	Define WBS	X								
2	ID Program Organization Structure	X								X
3	Company integration of EVMS/WBS/organization structure	X								
4	ID Overhead control POC					X				
5	Integrate Program WBS & organization structure	X								
PLANNING & BUDGETING										
6	Sequential scheduling of work		X							
7	ID products/milestones/goals		X							
8	Establish time-phased budget			X		X				
9	Establish significant cost elements	X		X					X	X
10	ID discrete work packages	X		X					X	N/A
11	Sum all work package budgets& planning packages			X						
12	ID LOE time-phased efforts			X					N/A	N/A
13	Establish overhead budgets for each significant organizational component					X				
14	ID management reserve and undistributed budget			X						
15	Reconcile program target cost goal with internal budgets			X						
ACCOUNTING										
16	Record direct costs				X					NA
17	Summarize direct costs into WBS				X					
18	Summarize direct costs into organization element				X					
19	Record indirect costs					NA				
20	ID unit costs, equivalent units costs or lot costs				NA					
21	EVMS cost accumulation by control accounts; cost performance measurement;								X	
ANALYSIS										
22	Control account monthly summary	X		X	X		X		N/A	X
23	Differences between planned and actuals, monthly		X				X		N/A	X
24	ID budgeted and actual indirect costs					X				
25	Summarize data elements and variances						X			
26	Implement management actions as result of EVM analysis	X					X			
27	Revise EAC based on performance data; compare with PMB	X				N/A	X		X	X
REVISIONS										
28	Incorporate authorized changes							X		
29	Reconcile budgets with prior budgets							X		
30	Control retroactive changes				X			X		
31	Prevent all but authorized budget changes							X		
32	Document changes to PMB							X		

LEGEND:	
FI	Fully Implemented
PI	Partially Impemented
NI	Not or minimumly Implemented

"Creating Customer-Focused Success"

Earned Value Management in the Federal Sector

Section 3.

EVM In The Civil Agencies

- DOD, NASA, DOE have a long history in EVM (waxes and wanes)
- New OMB emphasis on EVM (2001) resulted in a surge in its application
  - Now applicable to all agencies
  - Major acquisitions* (but being applied at much lower levels)
  - IT system especially impacted due to definition of major systems for IT (>$1M)
- GAO is up to speed and has started to examine EVM implementation and EVM information on agency programs

*** Major Acquisitions (aka Major Systems)**

- ✓ Importance to agency mission
- ✓ High development, operating or maintenance cost
- ✓ High risk
- ✓ High return
- ✓ Significant role in agency

EVM in the Civil Agencies (cont.)

- Civil Agencies (including FAA) are new to the game
  - Conceptual comprehension of EV, EVM, EVMS is low
- Primarily focus on IT and Systems (but should include construction)
- Using agency-based systems (in house EVM) vs. contractor-based for existing contracts and projects in mid acquisition
- Portfolio application (State, Justice)
- EVM planned for application on new contracts
- Increased training, new policies, focus on implementation and Exhibit 300 reporting

FAA Policy on EVM

- Required for programs designated as “major”
- Major contracts and subcontracts >$10M for DME (F&E)
  - Contract Performance Report
  - Integrated Master Schedule
  - Integrated Baseline Review
- Small contracts and subcontract (<$10M) may use EVM
- Report data monthly to Department project monitoring system

EVMS FAR Case

- OMB Proposed FAR Rule on EVM in work
  - Employ EVM on all major acquisitions
  - Conduct Integrated Baseline Review to verify technical content and realism of budget, resources and schedules
  - Contractor monthly reporting of EV
- Government acquisition plans must include
  - Management system used by the Government to monitor the contractor's effort.
  - Methodology to analyze and us EV data
  - Verification of compliance with the standard
- Even though FAA is exempt from the FAR it is expected that they will incorporate similar or identical language in their contracts

Importance of EVM to Federal Agencies

- Federal Acquisition Streamlining Act 1994, Title V Acquisition Management requires Agency Head to approve or define the Cost, Performance and Schedule goals for major acquisitions
  - CFO must evaluate the Cost goals
  - If project not within 90% of ***goals****, Agency Head shall
    - (1) determine if there is a continuing need for the project, and
    - (2) identify suitable actions to be taken, including termination.
- Clinger-Cohen Act of 1996
  - Establish processes for executive agencies to analyze, track, and evaluate the risks and results of major investments in IT
  - Report on the net program performance benefits achieved by agencies

*For FAA these are the JRC Baseline goals in terms of cost, schedule and scope

What OMB Requires

- Acquisition/Implementation Phase
  - Demonstrate satisfactory progress toward cost, schedule and performance goals
  - Use a performance-based acquisition management system that *meets the requirements* of ANSI/EIA Standard 748, Earned Value Management Systems
  - Development of WBS must include risk analysis and *Management Reserve* based on risk analysis.

- Operating Projects must employ operational analysis to track:
  - Actual annual O&M costs compared to original life-cycle estimates
  - Level or quality of performance /capability meets performance goals and user needs
  - EVMS may be used, but is not mandatory

EVM Requirements in the Business Case (Exhibit 300)

- Demonstrate use of an EVMS that meets ANSI/EIA Standard 748, for both *Government* and contractor costs, for those parts of the investment that require development efforts (e.g., prototypes and testing in the Planning Phase, and development efforts in the Acquisition Phase) and show how close the investment is to meeting the approved cost, schedule and performance goals.

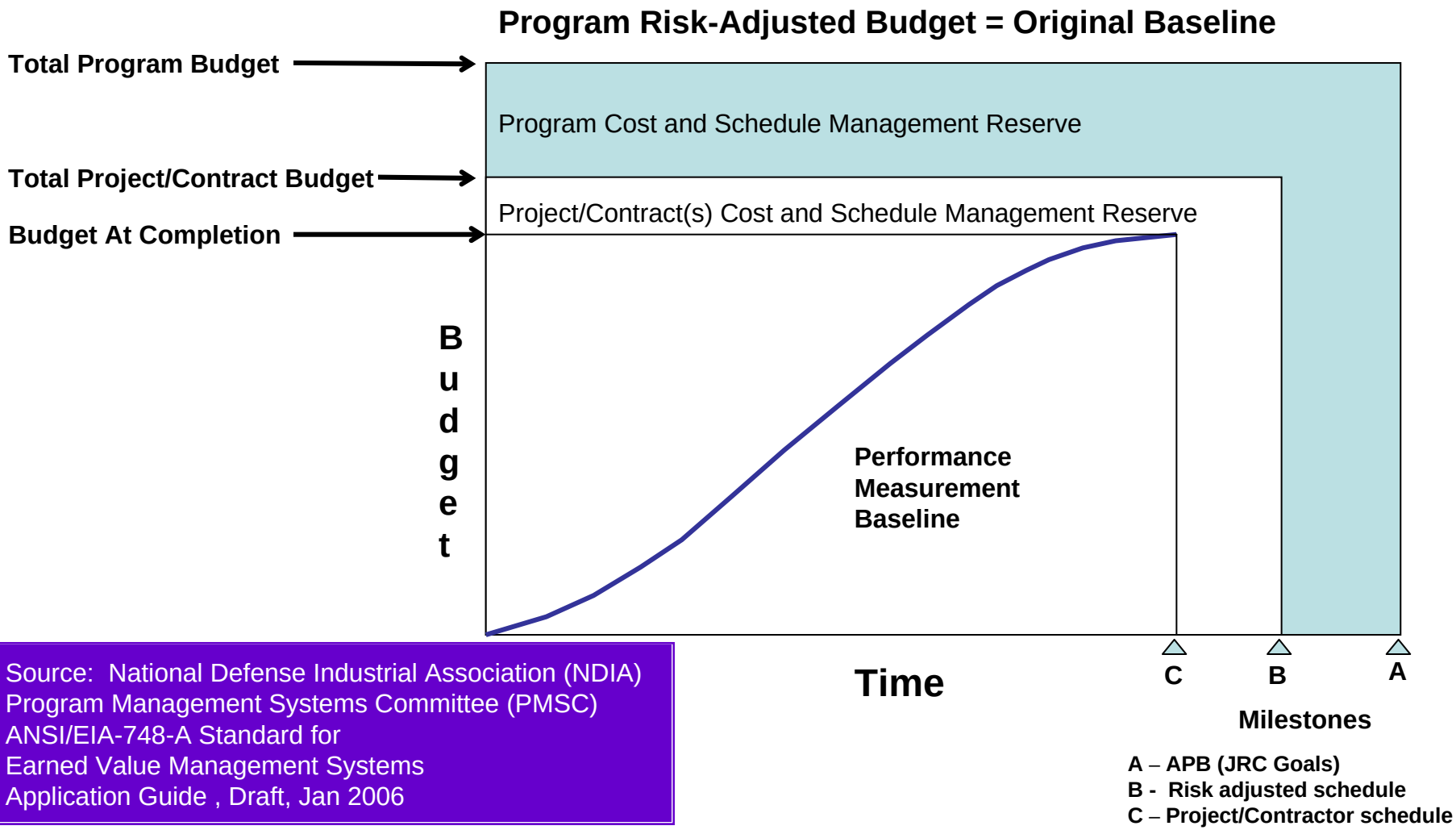
- Operational or steady state investments must track goals using Operational Analysis as defined in the Capital Programming Guide.

EVM In Specific Sections of Exhibit 300

- I.H.2 Original Baseline
  - Cost and schedule goals for phase or segment/module of project
  - Major project milestones
    - When will they occur and cost
    - Funding agency for each milestone
  - This baseline is include in all subsequent reports, even when OMB has approved changes shown in I.H.3

The original baseline is the program baseline (total budget, total cost, key milestones, key performance parameters) (JRC Baseline)

Program Budget Breakdown (Original Baseline)



Source: National Defense Industrial Association (NDIA) Program Management Systems Committee (PMSC) ANSI/EIA-748-A Standard for Earned Value Management Systems Application Guide , Draft, Jan 2006

EVM In Specific Sections of Exhibit 300 (cont.)

I.H.4.B Project Summary

- Budgeted Cost of Work Scheduled (BCWS)
- Budgeted Cost of Work Performed (BCWP)
- Actual Cost of Work Performed (ACWP)
- Cost curve plotting BCWS, BCWP and ACWP on monthly basis

I.H.4.B.4 Provide the following EVMS Analysis

- Cost Variance $ and %
- Cost performance index
- Schedule Variance $ and %
- Schedule Performance Index
- Two independent Estimate At Completion
- Variance at Completion for EACs ($ & %)
- Expected Funds to Completion
- Expected Completion Date

Projects may be at the useful segment level or total program level, but…Budget At Completion may not equal the total program budget

EVM In Specific Sections of Exhibit 300 (cont.)

I.H.4.C and D

C - Analysis of the reasons for cost and schedule variances of 10% or more

D - Provide performance variance

Explain whether IPT still expects to achieve performance goals. If not, explain reasons

I.H.4.E, F and G

E - Discuss estimate to complete (EAC)

- Two commonly used EAC formulas
- Rationale for the EAC chosen by IPT

F - Corrective actions with risk - How close to original goals will be result

G - Agency Head concurrence to continue project

New DoD EV Policy

- 7 Mar 2005 Ltr
  - Greater than $20M, all types of cost contracts
  - Implement New DiD and WBS Handbook
  - C/SSR rescinded (except on old contracts)
  - Integrated Baseline Reviews (IBRs) required
  - If on Price contracts, examine contract type

- Contract Performance Report (DiD-MGMT-81466)
- Integrated Master Schedule (DiD-MGMT-81650)
- DoD Work Breakdown Structure Handbook, MIL-HDBK-881 `

CPR Formats

- Contract Performance Report (DiD-MGMT-81466)
- FORMAT 1 - WORK BREAKDOWN STRUCTURE
  - Current month and cum by Product WBS
- FORMAT 2 - ORGANIZATIONAL CATEGORIES
  - Current month and cum by Organization
- FORMAT 3 – BASELINE
  - Budget Cost of Work Schedule…next 6 months and out
- FORMAT 4 – STAFFING
  - Man Months…next 6 months and out
- FORMAT 5 - EXPLANATIONS AND PROBLEM ANALYSES

CLASSIFICATION (When Filled In)

CONTRACT PERFORMANCE REPORT
FORMAT 1 - WORK BREAKDOWN STRUCTURE

DOLLARS IN

FORM APPROVED
OMB No. 0704-0188

1. CONTRACTOR
a. NAME
b. LOCATION (Address and ZIP Code)

2. CONTRACT
a. NAME
b. NUMBER
c. TYPE
d. SHARE RATIO

3. PROGRAM
a. NAME
b. PHASE
c. EVMS ACCEPTANCE
NO YES (YYYYMMDD)

4. REPORT PERIOD
a. FROM (YYYYMMDD)
b. TO (YYYYMMDD)

5. CONTRACT DATA

a. QUANTITY	b. NEGOTIATED COST	c. ESTIMATED COST OF AUTHORIZED UNPRICED WORK	d. TARGET PROFIT/ FEE	e. TARGET PRICE	f. ESTIMATED PRICE	g. CONTRACT CEILING	h. ESTIMATED CONTRACT CEILING	i. DATE OF OTB/OTS (YYYYMMDD)

6. ESTIMATED COST AT COMPLETION

	MANAGEMENT ESTIMATE AT COMPLETION (1)	CONTRACT BUDGET BASE (2)	VARIANCE (3)
a. BEST CASE			
b. WORST CASE			
MOST LIKELY			

7. AUTHORIZED CONTRACTOR REPRESENTATIVE
a. NAME (Last, First, Middle Initial)
b. TITLE
c. SIGNATURE
d. DATE SIGNED (YYYYMMDD)

8. PERFORMANCE DATA

ITEM (1)	CURRENT PERIOD BUDGETED COST WORK SCHEDULED (2)	CURRENT PERIOD BUDGETED COST WORK PERFORMED (3)	CURRENT PERIOD ACTUAL COST WORK PERFORMED (4)	CURRENT PERIOD VARIANCE SCHEDULE (5)	CURRENT PERIOD VARIANCE COST (6)	CUMULATIVE TO DATE BUDGETED COST WORK SCHEDULED (7)	CUMULATIVE TO DATE BUDGETED COST WORK PERFORMED (8)	CUMULATIVE TO DATE ACTUAL COST WORK PERFORMED (9)	CUMULATIVE TO DATE VARIANCE SCHEDULE (10)	CUMULATIVE TO DATE VARIANCE COST (11)	REPROGRAMMING ADJUSTMENTS COST VARIANCE (12a)	REPROGRAMMING ADJUSTMENTS SCHEDULE VARIANCE (12b)	REPROGRAMMING ADJUSTMENTS BUDGET (13)	AT COMPLETION BUDGETED (14)	AT COMPLETION ESTIMATED (15)	AT COMPLETION VARIANCE (16)
a. WORK BREAKDOWN STRUCTURE ELEMENT																
b. COST OF MONEY																
c. GENERAL AND																
d. UNDISTRIBUTED BUDGET																
e. SUB TOTAL (PERFORMANCE MEASUREMENT BASELINE)																
f. MANAGEMENT RESERVE																
g. TOTAL																

9. RECONCILIATION TO CONTRACT BUDGET BASE

a. VARIANCE ADJUSTMENT																
b. TOTAL CONTRACT VARIANCE																

DD FORM 2734/1, MAR 05

LOCAL REPRODUCTION AUTHORIZED.

CLASSIFICATION (When Filled In)

Integrated Master Schedule DiD-MGMT-81650

- Detail data on – task, milestone, duration, % complete, relationship, float/slack, critical path, etc
- Identify the – constraints (finish no later than, etc), current schedule, baseline schedule, forecasted starts and finishes, etc
- Schedule Margin – considered part of the baseline!
- Schedule Risk Assessment Prediction with most likely, best/worst case estimates on remaining tasks
  - Assess critical and near critical path, margin erosion, and mitigation plans
  - Risk analysis within the IMS or within a separate risk tool
- Submit prior or concurrent with format 5 on CPR

Capital Programming Guide Supplement A-11, Part 7 June 2006

- Note, "FASA '94 required that Agency Heads manager the agency portfolio of major acq within 90 percent of the individual investment's cost, schedule and performance goals."
- "…therefore, provide …risk adjusted, most likely cost, schedule, and performance goals."
- "The program's risk-adjusted budget (PRB) establishes the baseline for reporting to OMB on program performance….the PRB is justified based on risk, and that the agency will fund the program at that level."
- "…program budget, expected outcomes and cost/schedule performance measurements are integrated with risk management."
- "Risks … for each WBS element should be identify, analyzed, and quantified in terms of potential cost to the program."
- "the cost of the risk occurrence is added to the BAC …is the risk adjusted budget

Capital Programming Guide Supplement A-11, Part 7 June 2006

- "OMB guidance on benefit-cost analysis includes: …Perform Risk and Sensitivity Analysis
- "Risks identified in the IBR are documented, analyzed, and risk-handling plans are developed and are included in an overall program risk register."
- "…both gov development efforts and contractor development efforts …two EVM systems must be consolidated …for total … visibility."
- "The agency EVM process should be consistent with the guidelines and processes in the NDIA EVMS related Guides."
- Appendix 5 Risk Management
  - Defines risk with positive or negative effect on project objective
  - Costs to be quantified by determining expected value. "These costs must be included in cost estimates."

Capital Programming Guide Supplement A-11, Part 7 June 2006

- Glossary – Program Risk-Adjusted Budget (PRB)

  "The total budget that represents the amount of resources and schedule expected to be needed to cover the risk of cost an schedule overruns to meet a 90 percent probability of project/program success. It is an amount held at a level above the program level to be released to the program when needed to cover risk that was not identifiable through an IBR, but that history indicates will cause costs and schedule overruns from the Performance Measurement Baseline through no fault of the program management process."

- Some confusion around the "90 percent probability"
- Were are the funds held? What level of funding is provided to the program? …practice will evolve

- Pull out your Triple Gold Card

Triple Gold Card
Cost, Schedule & Performance

"Creating Customer-Focused Success"

"Triple" Gold Card ©
Quick Reference Guide
For EVM

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703-506-4600
www.MCRI.com

MCR's "TRIPLE" GOLD CARD

is provided as a quick reference and checklist. It follows in the tradition of the DAU GOLD CARD, but covers Cost, Schedule, and Performance (thus TRIPLE) while touching on all 5 major areas of EVMS. Additionally the CARD outlines MCR's Risk/Opportunity Indexes. You can obtain a PDF version of the CARD at www.MCRI.com

Earned Value Management is a methodology that considers a discrete project's scope (performance), time (networked schedule), resources (people and materials), and their related uncertainties (risks) in an integrated system which meets basic criteria. EVM System Guidelines (ANSI/EIA-748-A-2002) are grouped into five major categories

1. **Organization** – define work (WBS), organization (OBS), and related integrated processes ...
2. **Planning, Scheduling, and Budgeting** – develop discrete time-phased budget baseline which identifies work with physical products, milestones, performance goals, and other indicators of progress ...
3. **Accounting Considerations** – valid, timely, and auditable information ...
4. **Analysis and Management Reports** – at least monthly at control account and other levels ...
5. **Revisions and Data Maintenance** – authorized changes are controlled, timely ...

Define Scope (Performance) and Organize

Work Breakdown Structure (WBS)

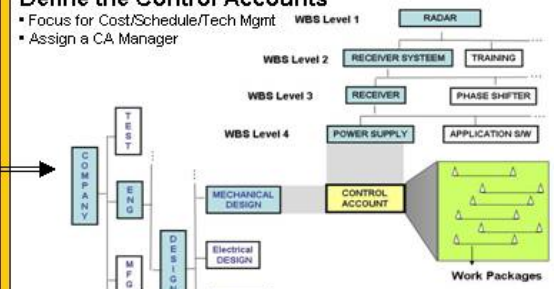
Level One – Product - entire product being built or delivered
Level Two – Major Element (Segment) and Sub-Systems
Level Three – Subordinate Components (Prime Items), individual components or assemblies subordinate to Level Two
Levels 4 to X - Subproducts at lower levels until material/work effort is found
Elements numbered in a logical and consistent manner
Example: WBS element 1.1.3
1.2.3 Represents Level 1
1.**2**.3 Represents Level 2
1.2.**3** Represents Level 3

Organizational Breakdown Structure (OBS)

Level One – Performing Organization - entire organization responsible for performing the work
Level Two – Major organization elements, sub contractors, or IPTs
Level Three – Subordinate organizations responsible for primary items within the WBS or sub Integrated Product/Process Teams (IPTs)
Levels 4 to x - Sub organizations responsible for work packages

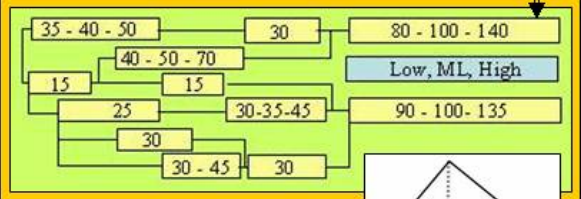
Define the Control Accounts

- Focus for Cost/Schedule/Tech Mgmt
- Assign a CA Manager

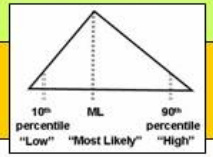


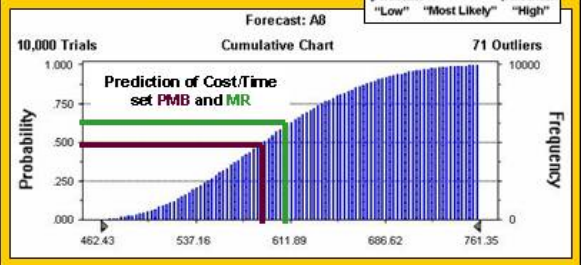
- Control Accounts breakout into work and planning packages

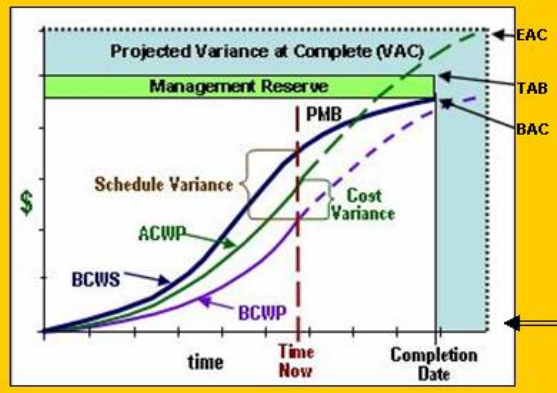
Develop Network and Budgets



PM team iterates tech, schedule, and costs given risks and opportunities. Determines range of possibilities, selects path and confidence level







Establish Baseline and Track

- ☐ Baseline is set, then an Intergraded Baseline Review (IBR) is conducted
- ☐ Cost, Schedule, Performance along with risks and opportunities are tracked
- ☐ Variances are analyzed, they are neither good or bad, but variations that indicate areas that might need management action
- ☐ Changes are managed through a configuration control process
- ☐ PM may Replan as necessary within scope or Reprogram to new scope

MCR's "TRIPLE" GOLD CARD ©

References

Includes DAU Gold Card info

Checklist by Guidelines

TERMINOLOGY

NCC	Negotiated Contract Cost	Contract price less profit / fee(s)	
AUW	Authorized Unpriced Work	Work contractually approved, but not yet negotiated / definitized	
CBB	Contract Budget Base	Sum of NCC and AUW	
OTB	Over Target Baseline	Sum of CBB and recognized overrun	
TAB	Total Allocated Budget	Sum of all budgets for work on contract = NCC, CBB, or OTB	
BAC	Budget At Completion	Total budget for total contract thru any given level	
PMB	Performance Measurement Baseline	Contract time-phased budget plan	
MR	Management Reserve	Budget withheld by Ktr PM for unknowns / risk management	
UB	Undistributed Budget	Broadly defined activities not yet distributed to CAs	
CA	Control Account	Lowest CWBS element assigned to a single focal point to plan & control scope / schedule / budget	
WP	Work Package	Near-term, detail-planned activities within a CA	
PP	Planning Package	Far-term CA activities not yet defined into WPs	
BCWS	Budgeted Cost for Work Scheduled	Value of work planned to be accomplished	= PLANNED VALUE
BCWP	Budgeted Cost for Work Performed	Value of work accomplished	= EARNED VALUE
ACWP	Actual Cost of Work Performed	Cost of work accomplished	= ACTUAL COST
EAC	Estimate At Completion	Estimate of total cost for total contract thru any given level, may be generated by Ktr, PMO, DCMA, etc. = $EAC_{Ktr/PMO/DCMA}$	
LRE	Latest Revised Estimate	Ktr's EAC or EAC_{Ktr}	
SLPP	Summary Level Planning Package	Far-term activities not yet defined into CAs	
TCPI	To Complete Performance Index	Efficiency needed from 'time now' to achieve an EAC	

Revisions and Data Maintenance

- ☐ CCB approval is required for changes to scope, schedule or budget Develop realistic CA EACs integrated with tech, cost, and schedule risks/opportunities. Establish Risk baseline (see Risk/Opp Index)
- ☐ Mitigation plans have triggers, are included in PMB and tied to metrics

Tech Performance Measures (TPM) and EV Techniques

goes to 1 at 80% confidence in Cost and/or Schedule

- Similar Index can be calculated for Opportunity (other side of range)
  - *Opportunity Range = CBB - CPD* $_{20\%}$

DAU Gold Card References

VARIANCES Favorable is Positive, Unfavorable is Negative

CV = BCWP - ACWP CV % = (CV / BCWP) × 100

SV = BCWP - BCWS SV % = (SV / BCWS) × 100

VAC = BAC - EAC

ES Favorable is > 1.0, Unfavorable is < 1.0

CPI = BCWP / ACWP

SPI = BCWP / BCWS

VS_{CUM} / BAC) × 100

VP_{CUM} / BAC) × 100

VP_{CUM} / BAC) × 100

ETION *

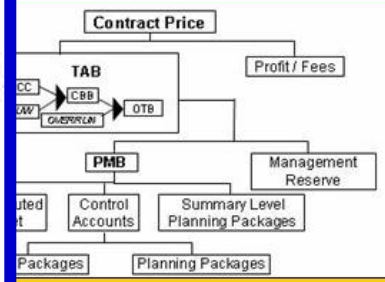
als to Date + [(Remaining Work) / (Efficiency Factor)]

$ACWP_{CUM}$ + [(BAC – $BCWP_{CUM}$) / CPI_{CUM}] = BAC / CPI_{CUM}

$ACWP_{CUM}$ + [(BAC – $BCWP_{CUM}$) / (CPI_{CUM} · SPI_{CUM})]

ORMANCE INDEX (TCPI) *

A Remaining / Cost Remaining = (BAC – $BCWP_{CUM}$) / (EAC – $ACWP_{CUM}$)



	Cost	Contract price less profit / fee(s)	
	Work	Work contractually approved, but not yet negotiated / definitized	
		Sum of NCC and AUW	
		Sum of CBB and recognized overrun	
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	n	Total budget for total contract thru any given level	
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EVM – Definition and Guidelines

what was known as criteria

"Creating Customer-Focused Success"

Earned Value Management is a methodology that considers a discrete project's scope (performance), time (networked schedule), resources (people and materials), and their related uncertainties (risks) in an integrated system which meets basic criteria. EVM System Guidelines (ANSI/EIA-748-A-2002) are grouped into five major categories

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MCR's "TRIPLE" GOLD
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in the tradition of the DAU GOLD CARD
Schedule, and Performance (thus TRIP
on all 5 major areas of EVMS. Addition
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Level One – Product - entire product being built or delivered
Level Two – Major Element (Segment) and Sub-Systems
Level Three – Subordinate Components (Prime Items), individual components

Define the Control Accounts
- Focus for Cost/Schedule/Tech Mgmt
- Assign a CA Manager

WBS Level 1
RADAR

- Cost, Schedule, Performance along with risks and opportunities are tracked
- Variances are analyzed, they are neither good or bad, but variations that indicate areas that might need management action
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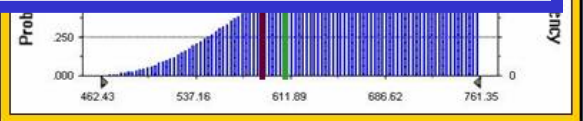

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The Work and Organization
Need for Breakdown Structures

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Quick Reference Guide
For EVM

Work Breakdown Structure (WBS)

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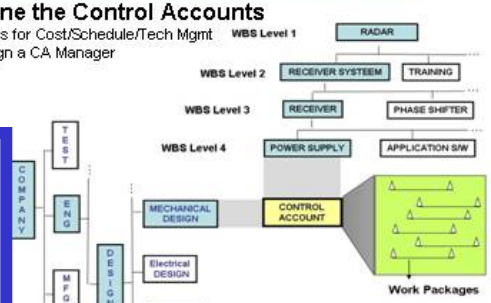
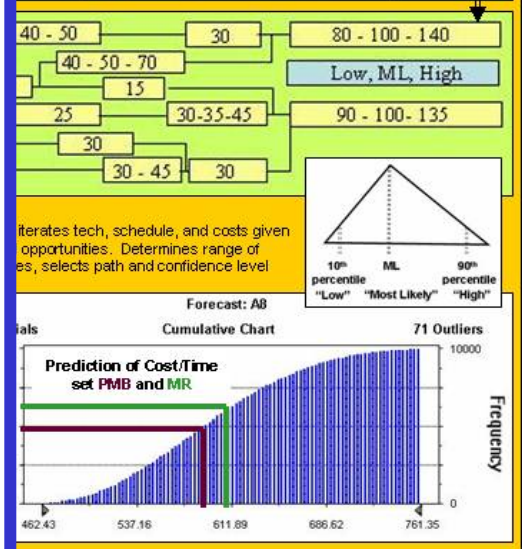
Elements numbered in a logical and consistent manner

Define the Control Accounts
- Focus for Cost/Schedule/Tech Mgmt
- Assign a CA Manager



- Control Accounts breakout into work and planning packages

velop Network and Budgets



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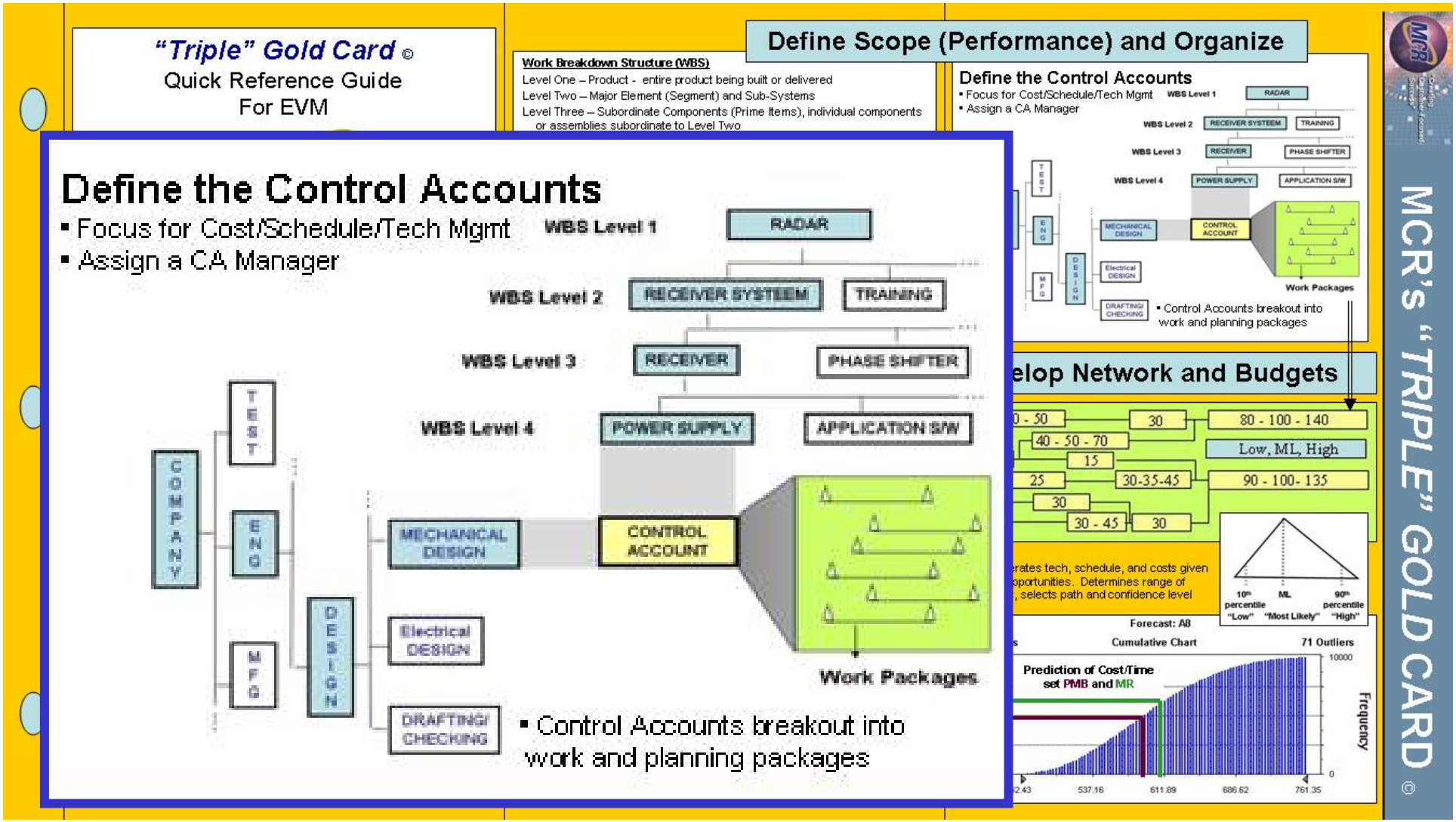
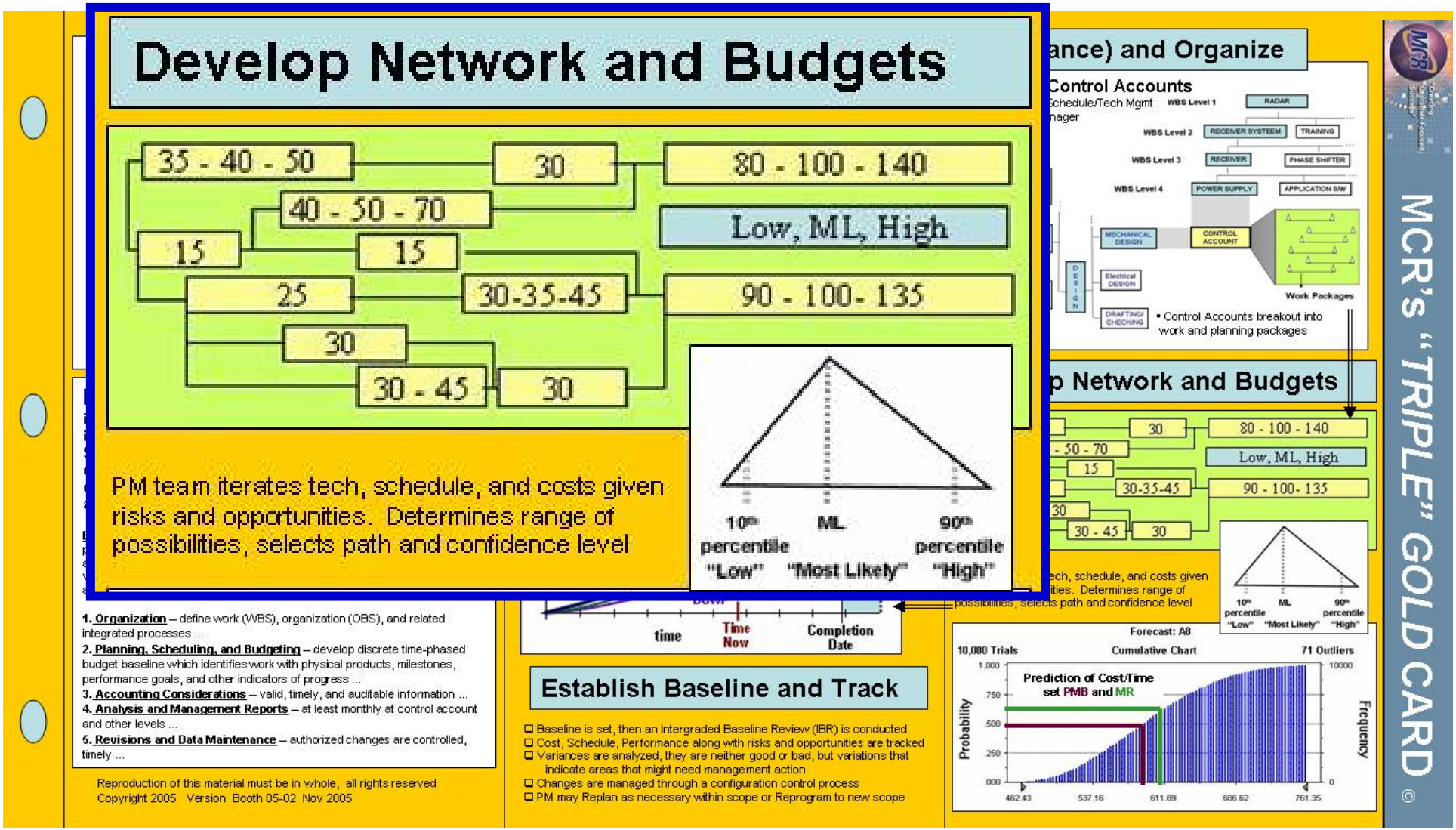
The Control Account (CA)
Schedule and Cost (budget)

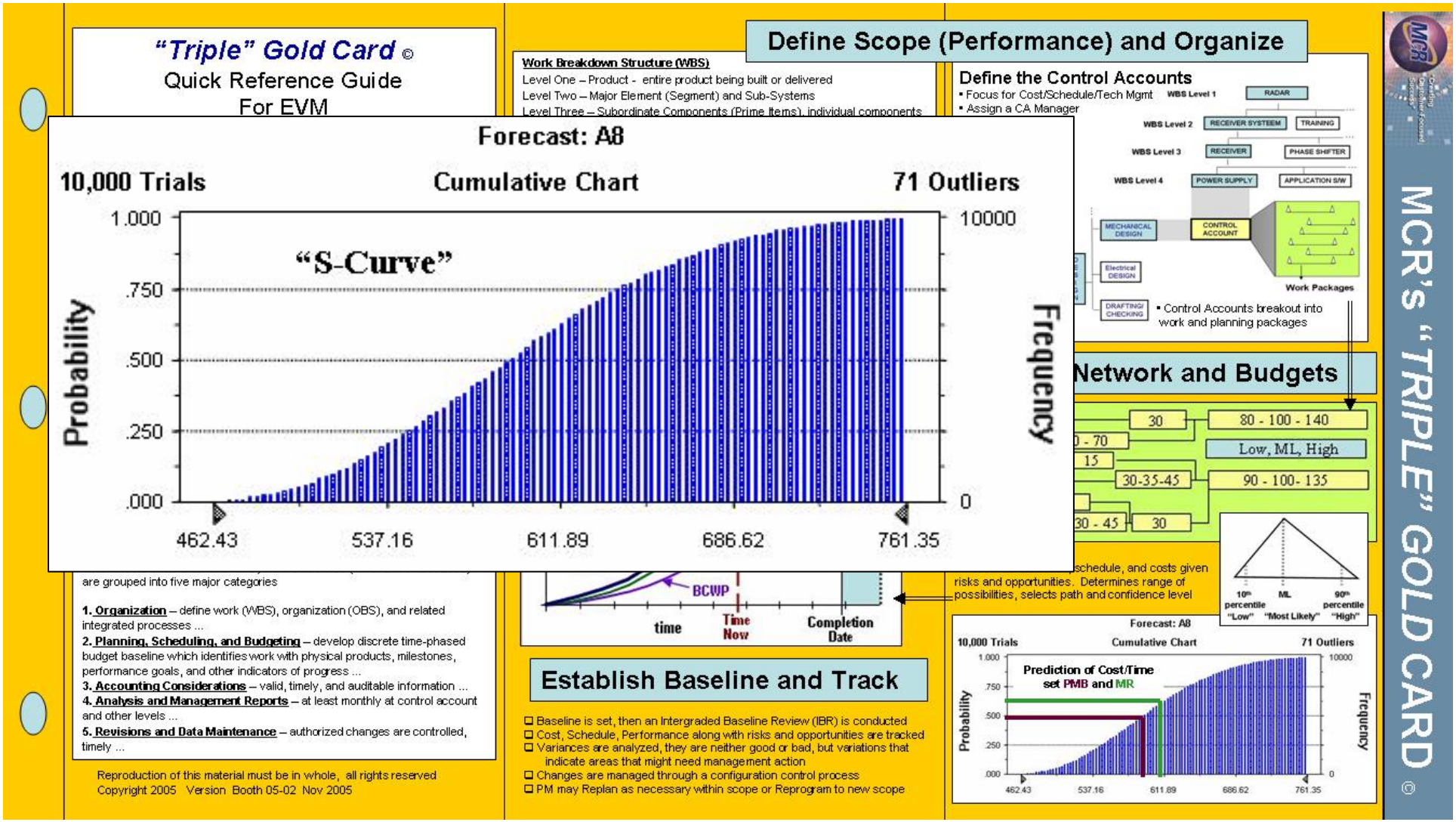


Break down to Work Packages

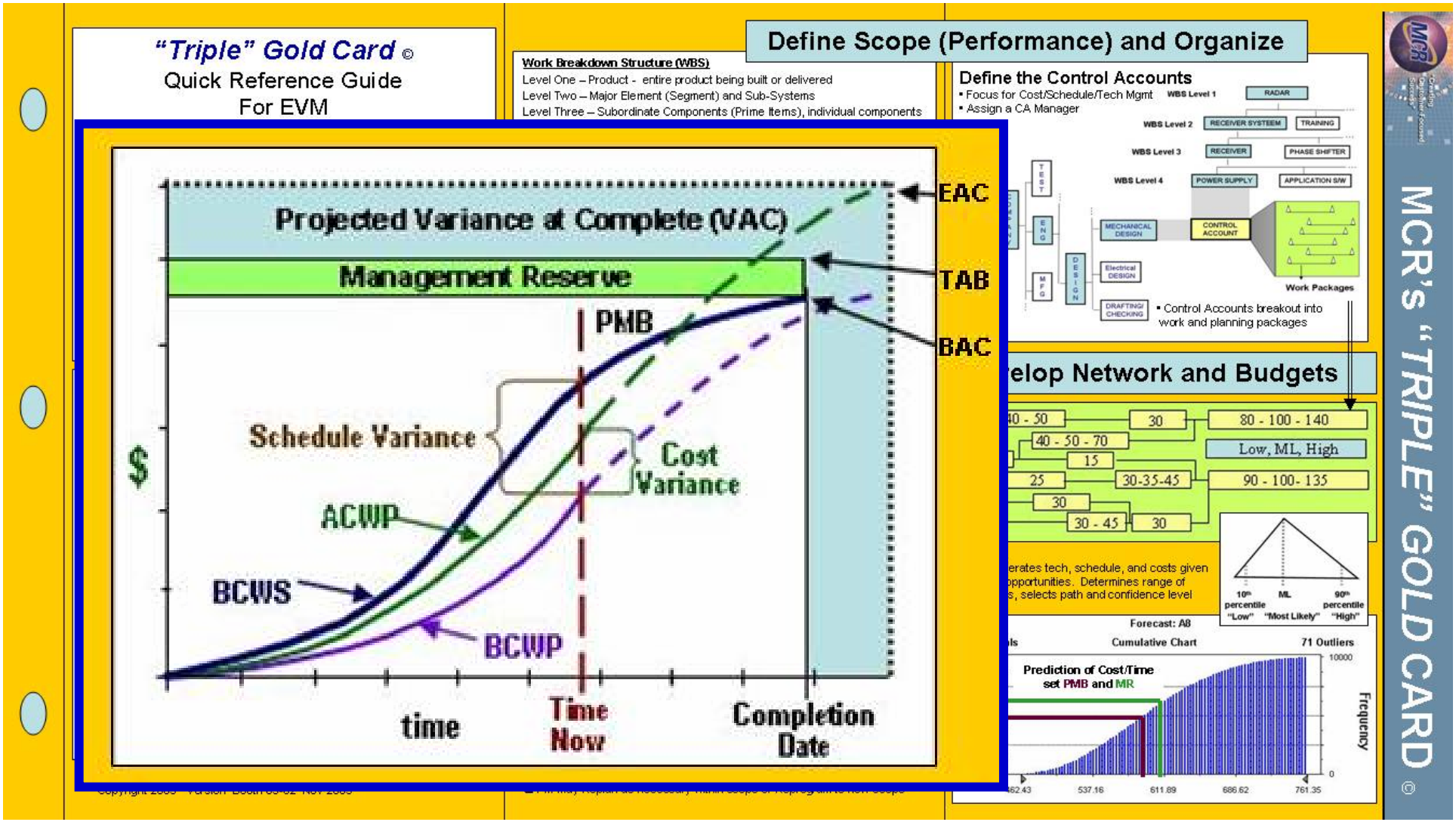
Select a path for the baseline



Triple Gold Card
Cost, Schedule & Performance



Establish and Track Baseline
compare BCWS/BCWP/ACWP



References

Includes DAU Gold Card info

Checklist by Guidelines

Organization

- ☐ WBS top level clearly describes one end product or deliverable
- ☐ The WBS represents the entire scope of work and represents products and not budget categories, organizations, personnel, tasks, functions, or project phases
- ☐ Each WBS subordinate element has only one parent
- ☐ Each subcontracted effort is assigned to a single WBS element (unless subcontractor is responsible for multiple components)
- ☐ Work Packages are not identified as WBS elements;
- ☐ CA is the point of MANAGEMENT CONTROL and ANALYSIS

Planning, Scheduling, and Budgeting

- ☐ All tasks have unique names, with milestones representing key events
- ☐ Work Packages average less than < 90 days
- ☐ Planning Packages are usually < one year and most often are tied to a Rolling Wave; the Rolling Waves are tied to significant project events
- ☐ Methods selected to measure work accomplished against plan must be objective and meaningful
- ☐ Schedule tasks are derived from a product-based WBS
- ☐ Schedule networks are created by linking lowest level tasks only
- ☐ Each schedule task has at least one predecessor and at least one successor (Exceptions: first and last task or external milestones)
- ☐ Use of schedule lags/leads is minimal; a lag/lead may be injected into the schedule network only for a specific purpose, not as shortcuts to identifying logical sequences of events or to override event sequencing
- ☐ Use of task constraints (Must Start On, etc.) is minimal, usually only for key contractual milestones
- ☐ Stakeholders validate Schedule Scope, Task Logic, and Durations
- ☐ Network critical path (+some float) focus of schedule/SPI analysis
- ☐ Track schedule metrics to assess goodness of schedule, include start/finish slips, tasks near critical path, float/slack, etc
- ☐ Pessimistic/Most Likely/Optimistic estimates are made for costs and time
- ☐ MR is based on risks and opportunities

Accounting Considerations

- ☐ WBS lowest elements are broken down into convenient 'packages' which are used to group, summarize/monitor elements of cost (i.e., labor, material, ODCs
- ☐ Estimated actuals are utilized to assure realistic actual costs in a timely manner

Analysis and Management Reports

- ☐ Reporting is at lowest WBS level necessary for effective management
- ☐ LOE is extracted when evaluating actual progress and performance
- ☐ EAC analysis is based on time/cost estimates adjusted for risks/opportunity
- ☐ Project MR 'burn down' rates with assumptions regarding potential distribution

Revisions and Data Maintenance

- ☐ CCB approval is required for changes to scope, schedule or budget Develop realistic CA EACs integrated with tech, cost, and schedule risks/opportunities. Establish Risk baseline (see Risk/Opp Index)
- ☐ Mitigation plans have triggers, are included in PMB and tied to metrics

Tech Performance Measures (TPM) and EV Techniques

- ☐ Baseline and Track TPMs and relate to measurement technique
- ☐ Establish tolerance bands for TPMs, track and turn into indexes
- ☐ Assign Discrete Effort (DE) that produces a product using:
  - Weighted Start/Finish Milestones on short tasks
    - 0/100, 50/50 or other breakout
  - % Complete on longer tasks with subjective inch stones
    - Document what constitutes % completion
  - Interim Milestones internal to work package
  - Value taken based on established Standards
- ☐ Relate Apportioned Effort (AE) to related discrete tasks
- ☐ Minimize Level of Effort (LOE), which has no tangible product
  - ☐ Breakup LOE by Rolling Wave and tie to project milestone

MCR's Risk/Opportunity Indexes

STEPS for Cost or Schedule related Index at CA/Summary level

- Determine Range of estimate (can defined as 20% to 80% on cumulative probability distribution (CPD)
  - *Risk Range* = $CPD_{80\%}$ - $CPD_{20\%}$
  - Range is in dollars for Cost and time (days) for Schedule
  - The wider the range, the riskier (likely more uncertain) the program
- Determine where CBB falls in the range (distribution)
  - Assuming CBB (PMB + MR) equal or less than 80% confidence level
  - PM decides how much opportunity to take in baseline and sets MR
- Determine Risk Liability given the selected PMB and CPD
  - *Risk Liability Baseline (RLB)* = $CPD_{80\%}$ - *CBB*, should decrease over time
- Determine Risk Exposure Index (REI) = ratio of *1- (RLB/CBB)*
  - REI = .75 indicates CBB only covers 75% of estimate program value at 80% confidence level. Index goes to 1 at 80% confidence values
  - Contract Budget Base for Schedule is contractual end of contract
- Determine Risk Susceptibility Index (RSI) = ratio of *MR/(RLB + MR)*
  - RSI = .75 indicates MR can cover 75% of contract liability. Index goes to 1 at 80% confidence in Cost and/or Schedule
- Similar Index can be calculated for Opportunity (other side of range)
  - *Opportunity Range* = *CBB* - $CPD_{20\%}$

DAU Gold Card References

VARIANCES Favorable is Positive, Unfavorable is Negative

Cost Variance	CV	= BCWP - ACWP	CV % = (CV / BCWP) × 100
Schedule Variance	SV	= BCWP - BCWS	SV % = (SV / BCWS) × 100
Variance at Completion	VAC	= BAC - EAC	

PERFORMANCE INDICES Favorable is > 1.0, Unfavorable is < 1.0

Cost Efficiency	CPI	= BCWP / ACWP
Schedule Efficiency	SPI	= BCWP / BCWS

OVERALL STATUS

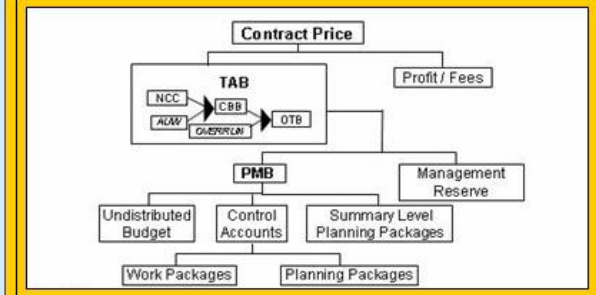
% Schedule	= ($BCWS_{CUM}$ / BAC) × 100
% Complete	= ($BCWP_{CUM}$ / BAC) × 100
% Spent	= ($ACWP_{CUM}$ / BAC) × 100

ESTIMATE AT COMPLETION

EAC	= Actuals to Date + [(Remaining Work) / (Efficiency Factor)]
EAC_{CPI}	= $ACWP_{CUM}$ + [(BAC – $BCWP_{CUM}$) / CPI_{CUM}] = BAC / CPI_{CUM}
$EAC_{Composite}$	= $ACWP_{CUM}$ + [(BAC – $BCWP_{CUM}$) / (CPI_{CUM} * SPI_{CUM})]

TO COMPLETE PERFORMANCE INDEX (TCPI)

$TCPI_{EAC}$ = Work Remaining / Cost Remaining = (BAC – $BCWP_{CUM}$) / (EAC – $ACWP_{CUM}$)

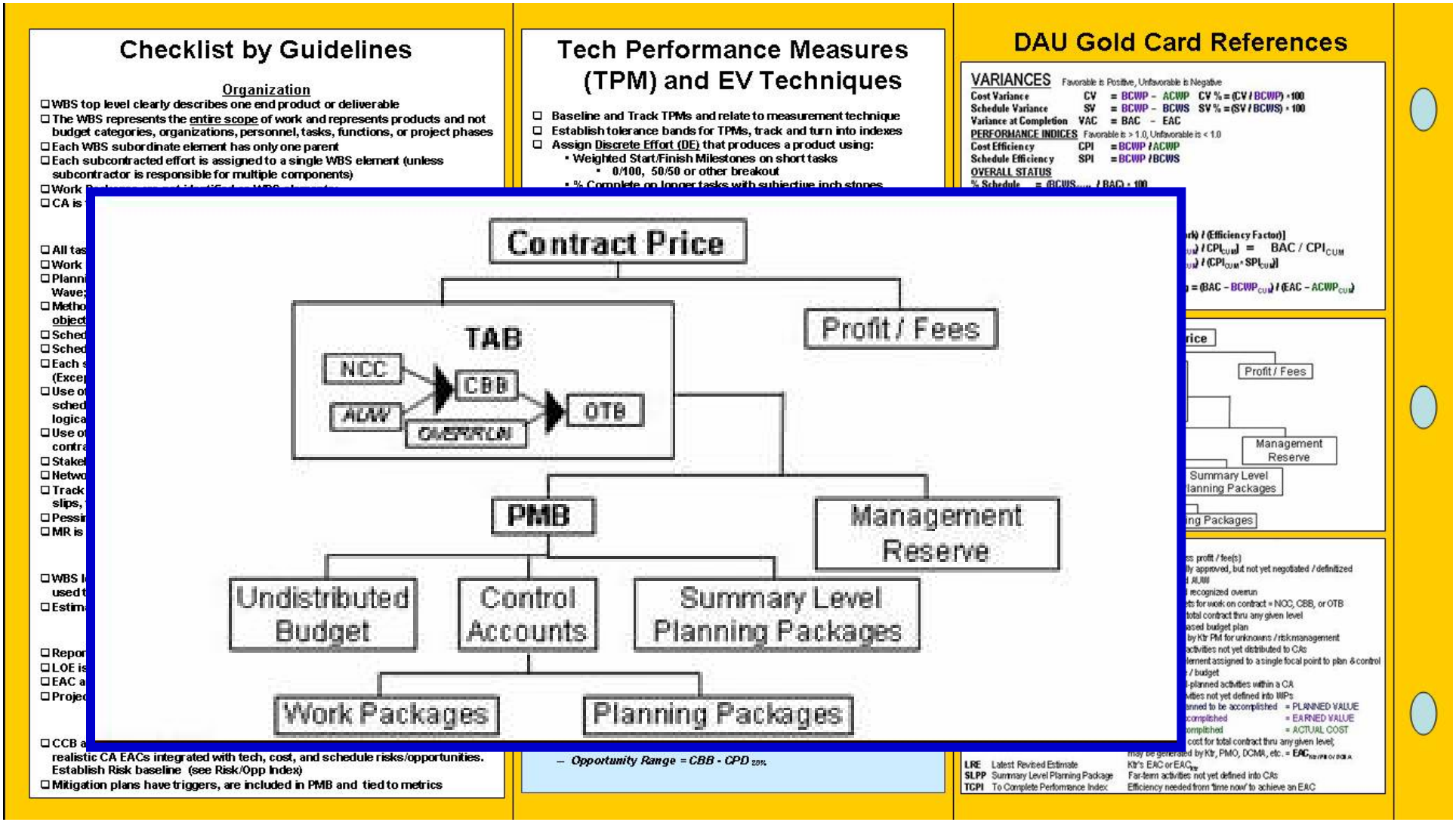


TERMINOLOGY

NCC	Negotiated Contract Cost	Contract price less profit / fee(s)	
AUW	Authorized Unpriced Work	Work contractually approved, but not yet negotiated / definitized	
CBB	Contract Budget Base	Sum of NCC and AUW	
OTB	Over Target Baseline	Sum of CBB and recognized overrun	
TAB	Total Allocated Budget	Sum of all budgets for work on contract = NCC, CBB, or OTB	
BAC	Budget At Completion	Total budget for total contract thru any given level	
PMB	Performance Measurement Baseline	Contract time-phased budget plan	
MR	Management Reserve	Budget withheld by Ktr PM for unknowns / risk management	
UB	Undistributed Budget	Broadly defined activities not yet distributed to CAs	
CA	Control Account	Lowest CWBS element assigned to a single focal point to plan & control scope / schedule / budget	
WP	Work Package	Near-term, detail-planned activities within a CA	
PP	Planning Package	Far-term CA activities not yet defined into WPs	
BCWS	Budgeted Cost for Work Scheduled	Value of work planned to be accomplished	= PLANNED VALUE
BCWP	Budgeted Cost for Work Performed	Value of work accomplished	= EARNED VALUE
ACWP	Actual Cost of Work Performed	Cost of work accomplished	= ACTUAL COST
EAC	Estimate At Completion	Estimate of total cost for total contract thru any given level, may be generated by Ktr, PMO, DCMA, etc.	= $EAC_{Ktr/PMO/DCMA}$
LRE	Latest Revised Estimate	Ktr's EAC or EAC_{Ktr}	
SLPP	Summary Level Planning Package	Far-term activities not yet defined into CAs	
TCPI	To Complete Performance Index	Efficiency needed from time now to achieve an EAC	

Contract Price

How EV breaks down the $$



The Indexes and Formulas

DAU References on COST calculations

Checklist by Guidelines

Organization

- ☐ WBS top level clearly describes one end product or deliverable
- ☐ The WBS represents the entire scope of work and represents products and not budget categories, organizations, personnel, tasks, functions, or project phases
- ☐ Each WBS subordinate element has only one parent
- ☐ Each subcontracted effort is assigned to a single WBS element (unless subcontractor is responsible for multiple components)
- ☐ Work Packages are not identified as WBS elements;
- ☐ CA is the point of MANAGEMENT CONTROL and ANALYSIS

Tech Performance Measures (TPM) and EV Techniques

- ☐ Baseline and Track TPMs and relate to measurement technique
- ☐ Establish tolerance bands for TPMs, track and turn into indexes
- ☐ Assign Discrete Effort (DE) that produces a product using:
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ESTIMATE AT COMPLETION #

- EAC = Actuals to Date + [(Remaining Work) / (Efficiency Factor)]
- $EAC_{CPI} = ACWP_{CUM} + [(BAC - BCWP_{CUM}) / CPI_{CUM}] = BAC / CPI_{CUM}$
- $EAC_{Composite} = ACWP_{CUM} + [(BAC - BCWP_{CUM}) / (CPI_{CUM} \cdot SPI_{CUM})]$

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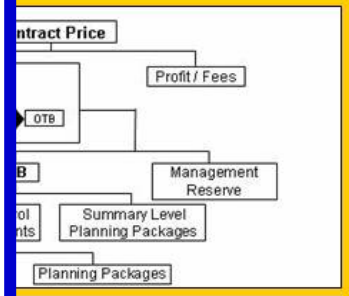
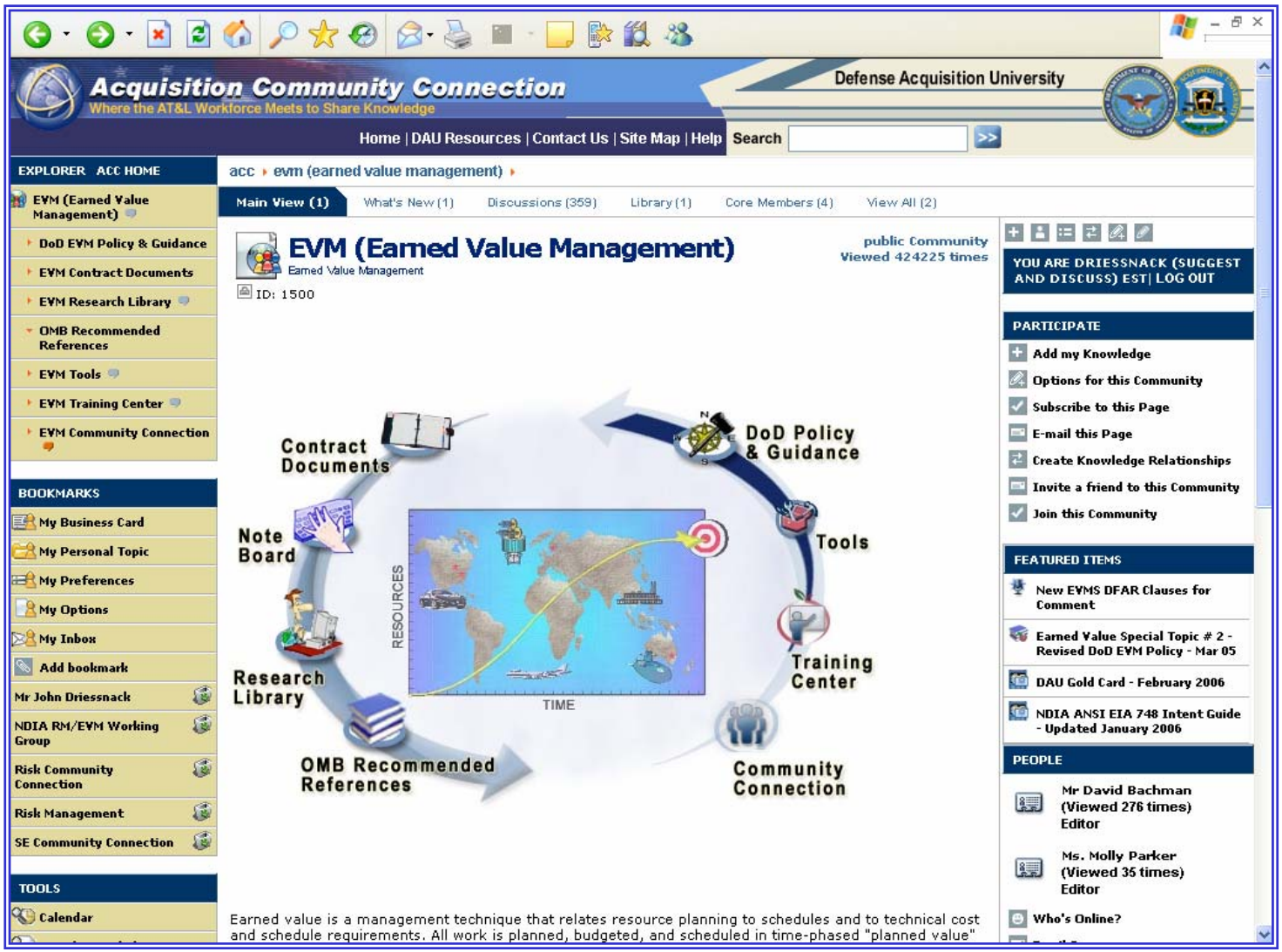


Good Source of Information

DAU http://ACC.DAU.mil



Summary

- Earned Value Management is program management methodology that provides a structured means to manage complex programs and projects
- EVM provides a accurate and reliable information on progress and performance
- Effective implementation results in a well-defined plan against which progress can be measured
- Prevents adding work without adding budget and deleting budget without deleting work
- Fosters management decisions within a framework of reality

Agenda

- 9:00 – 9:15 Introductions & Overview - Lehman
- 9:15 – 10:15 Intro to EVM/Evolving Policy – Driessnack
- 10:15 – 10:45 Break
- 10:45 – 11:15 EVM/Policy continued - Driessnack
- 11:15 – 12:00 1st Soupçon of Statistics – Dr Hulkower
- 12:00 – 1:15 Lunch (On Your Own)
- 1:15 – 2:00 Scheduling and Risk Analysis - Driessnack
- 2:00 – 2:30 2nd Soupçon of Statistics – Dr Hulkower
- 2:30 – 3:00 Break
- 3:00 – 3:30 Estimates part 1 - Driessnack
- 3:30 - 4:00 Estimates part 2 - Dr Hulkower

"Creating Customer-Focused Success"

A Soupçon of Statistics for Cost Analysts

Charts by Stephen A. Book, Ph.D.

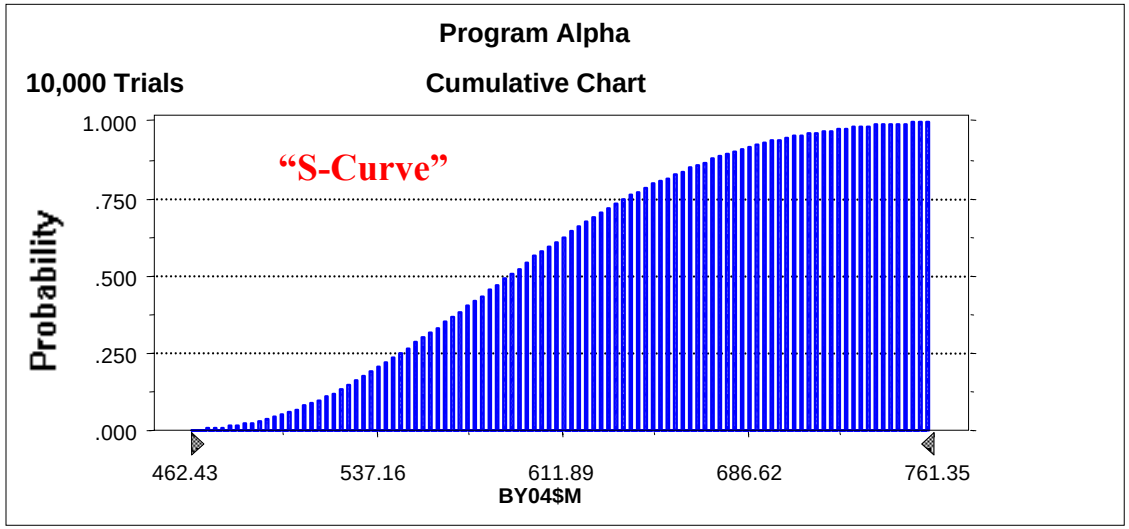
Outline

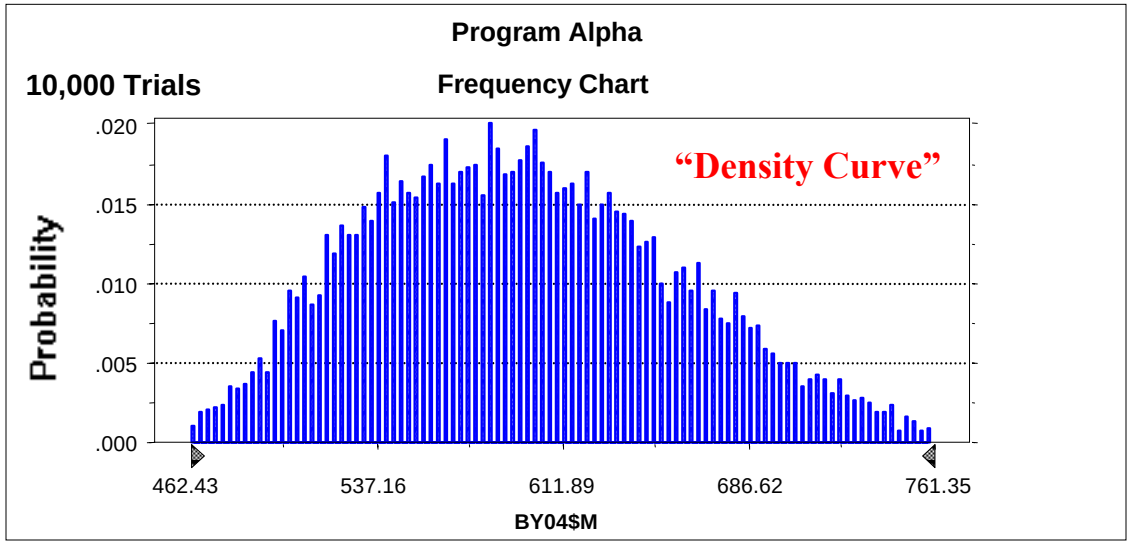
- What a Cost estimate Looks Like
- Risk Analysis in the Estimating Process
- “Best estimate” of project cost
- The cost-risk imperative
- Tools to use

What a Cost Estimate Looks Like

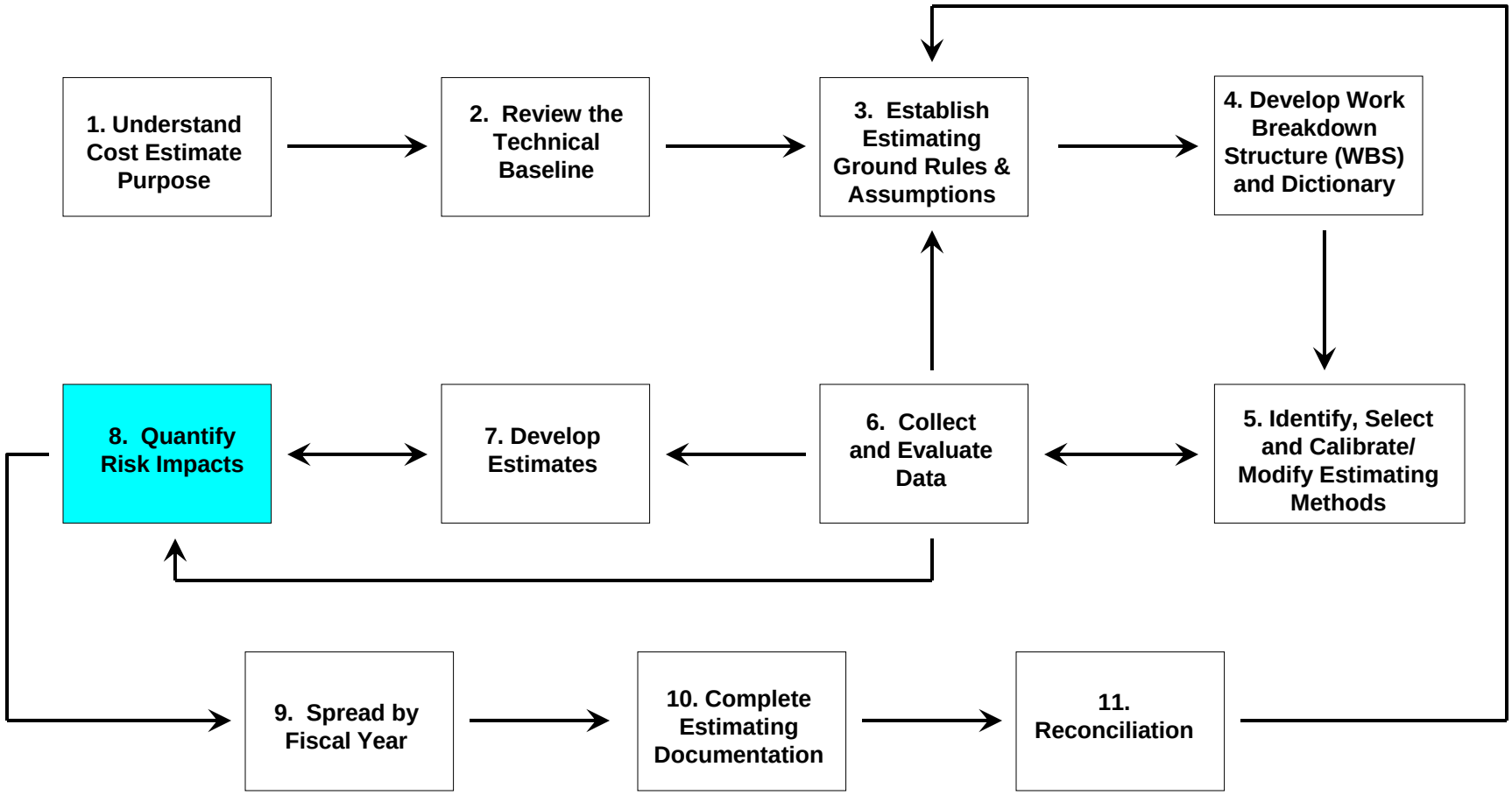
Percentile	Value
10%	516.81
20%	538.98
30%	557.85
40%	575.48
50%	592.72
60%	609.70
70%	629.19
80%	650.97
90%	683.01

Statistics	Value
Trials	10,000
Mean	596.40
Median	592.72
Mode	---
Standard Deviation	63.18
Range Minimum	450.19
Range Maximum	796.68





Estimating Process Flow



"Point" Cost Estimates

- Funding organizations seek "single best estimate" for
  - Cost/performance tradeoff studies
  - Benefit/cost analyses
  - Source selections
  - Budget planning
- But program cost is nebulous, heavily impacted by
  - Technological (im)maturity
  - Software requirements
  - Programmatic considerations
  - Schedule slips
  - Unforeseen events

"Point" Cost Estimates (Cont'd)

- **While "point" cost estimates are not "correct", "actual" program cost falls within some range surrounding the "best" estimate (with some degree of confidence)**
  - **The best we can hope to do is to understand the uncertainty**
  - **Understanding the uncertainty will help us make provision for it**

Naïve "Roll-Up" Procedure

- **List cost elements in a WBS**
  - **Calculate "best estimate" of cost for each WBS element**
  - **Sum all best estimates**
  - **Define result to be "point estimate" of total project cost**
- **Unfortunately, it turns out that things are not as simple as they seem – there are a lot of problems with this approach**

1st Problem: What Does the Term "Point Estimate" Mean?

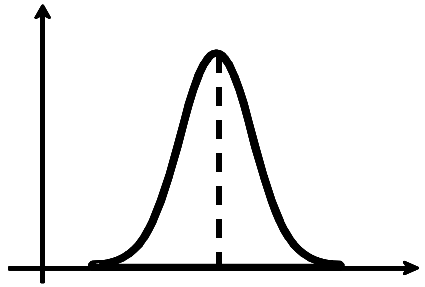
- Is the "point estimate" the …
  - "Most likely" cost? ("Mode")
  - 50th percentile cost? ("Median")
  - Expected cost? ("Mean")
  - 4th percentile cost?
  - Something else?
- What does it mean to you?
- When estimating costs of complex hardware/software systems, all these numbers are almost always different

Solution: Model Costs Statistically

- **While it is being estimated, "actual" program cost is an uncertain quantity**
  - **The "point" or "best" estimate is not the only possible estimate – this means that other estimates are "worse"**
  - **Use of phrase "most likely cost" implicitly assumes that other cost levels are "less likely"**
  - **"Most likely (mode)," "50th percentile (median)," and "expected value (mean)," are statistical terms characteristic of probability distributions**
- **This terminology implies that costs are statistical in nature and are defined by their probability distributions**

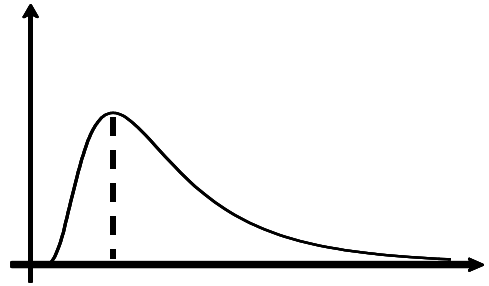
WBS-Element Probability Distributions

Low Risk

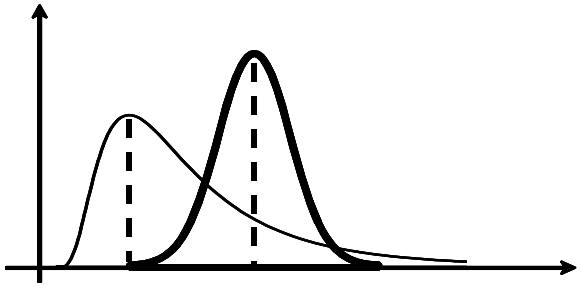


Best Estimate

High Risk

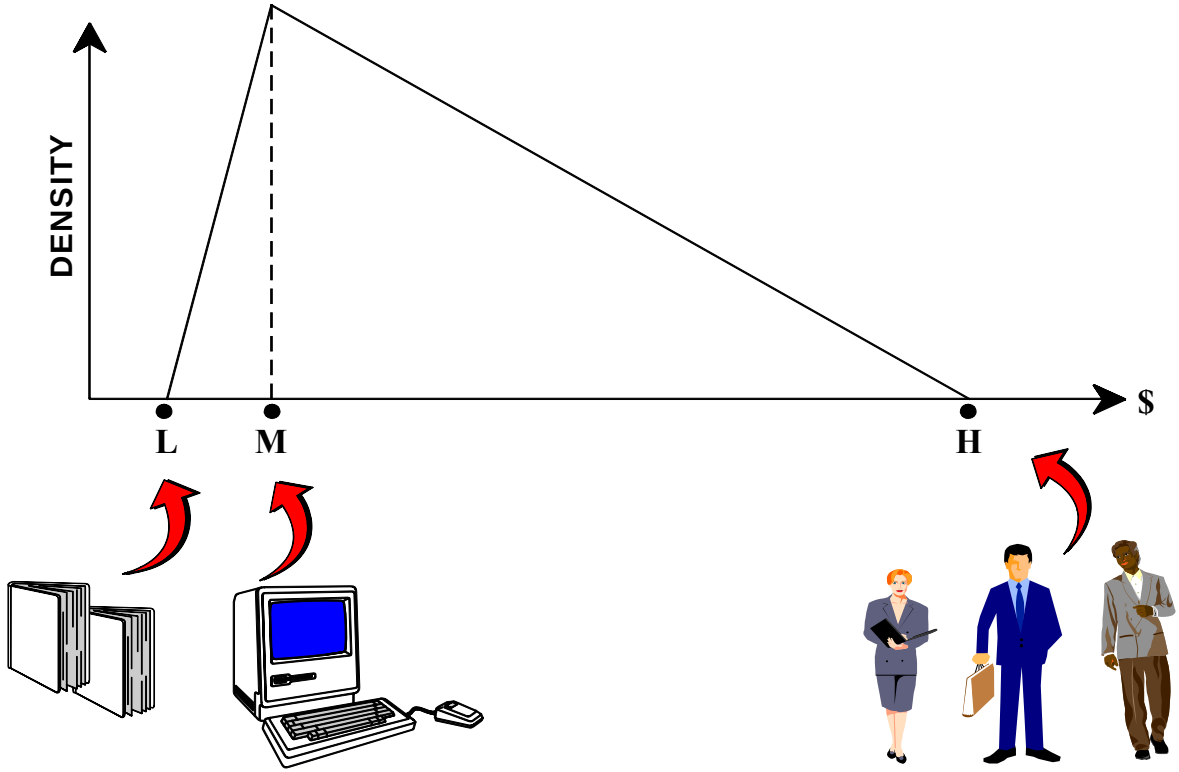


Best Estimate



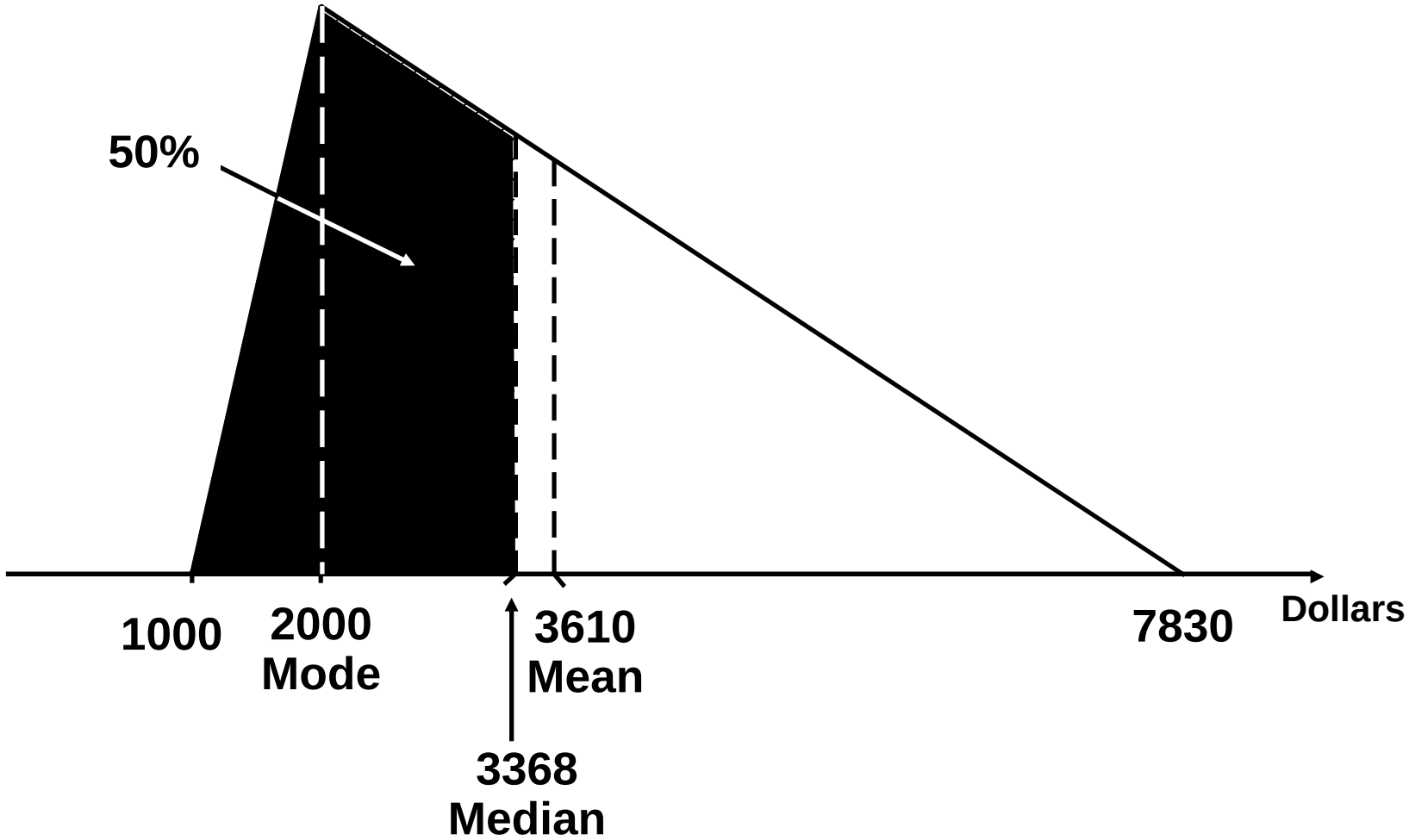
Low Cost, High Risk vs. High Cost, Low Risk

Triangular Distribution of WBS-Element Cost

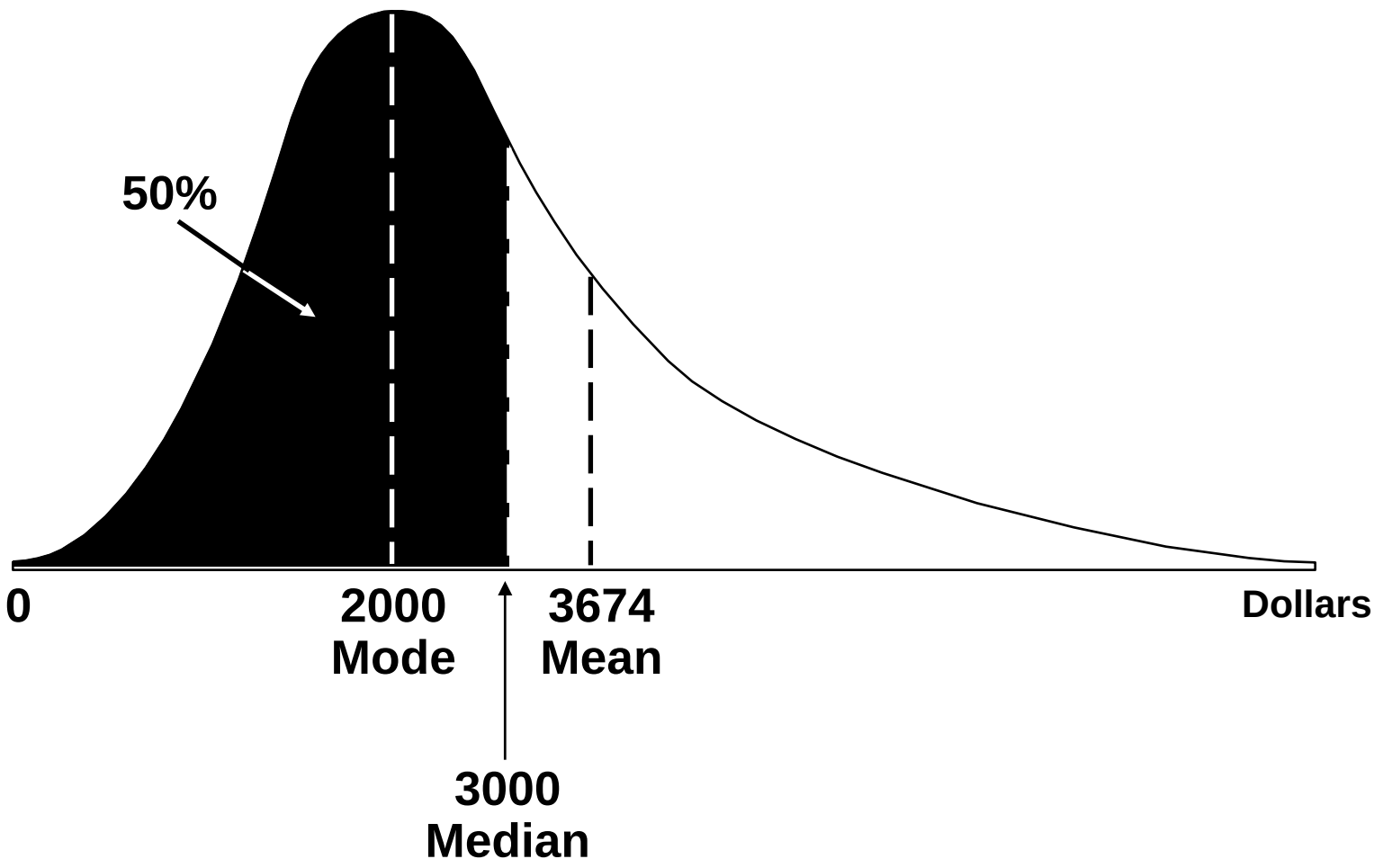


Optimistic Cost **Best-Estimate Cost (Mode)** **Cost Implication of Technical, Programmatic Assessment**

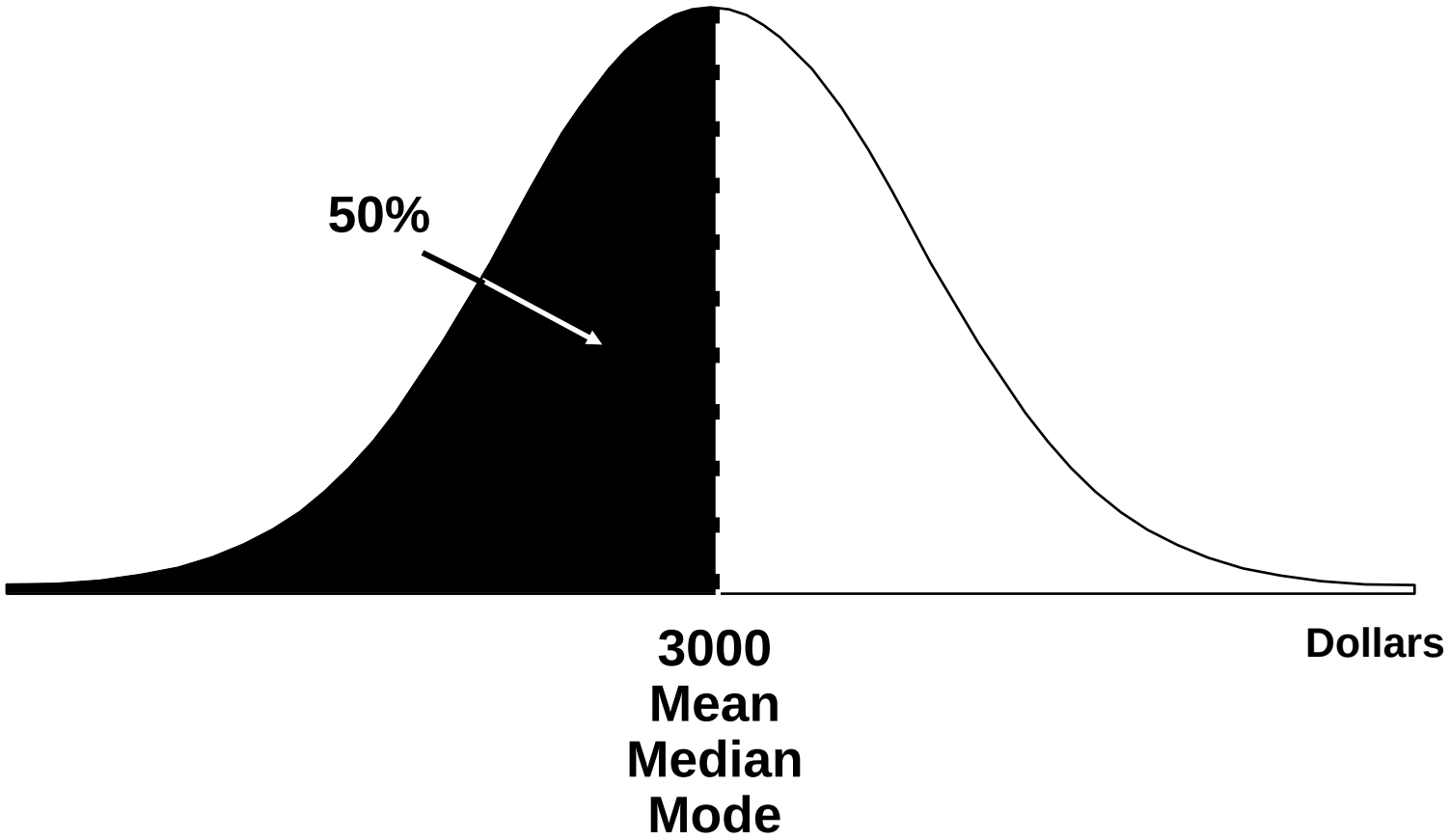
Statistics of Triangular Distributions



Statistics of Lognormal Distributions

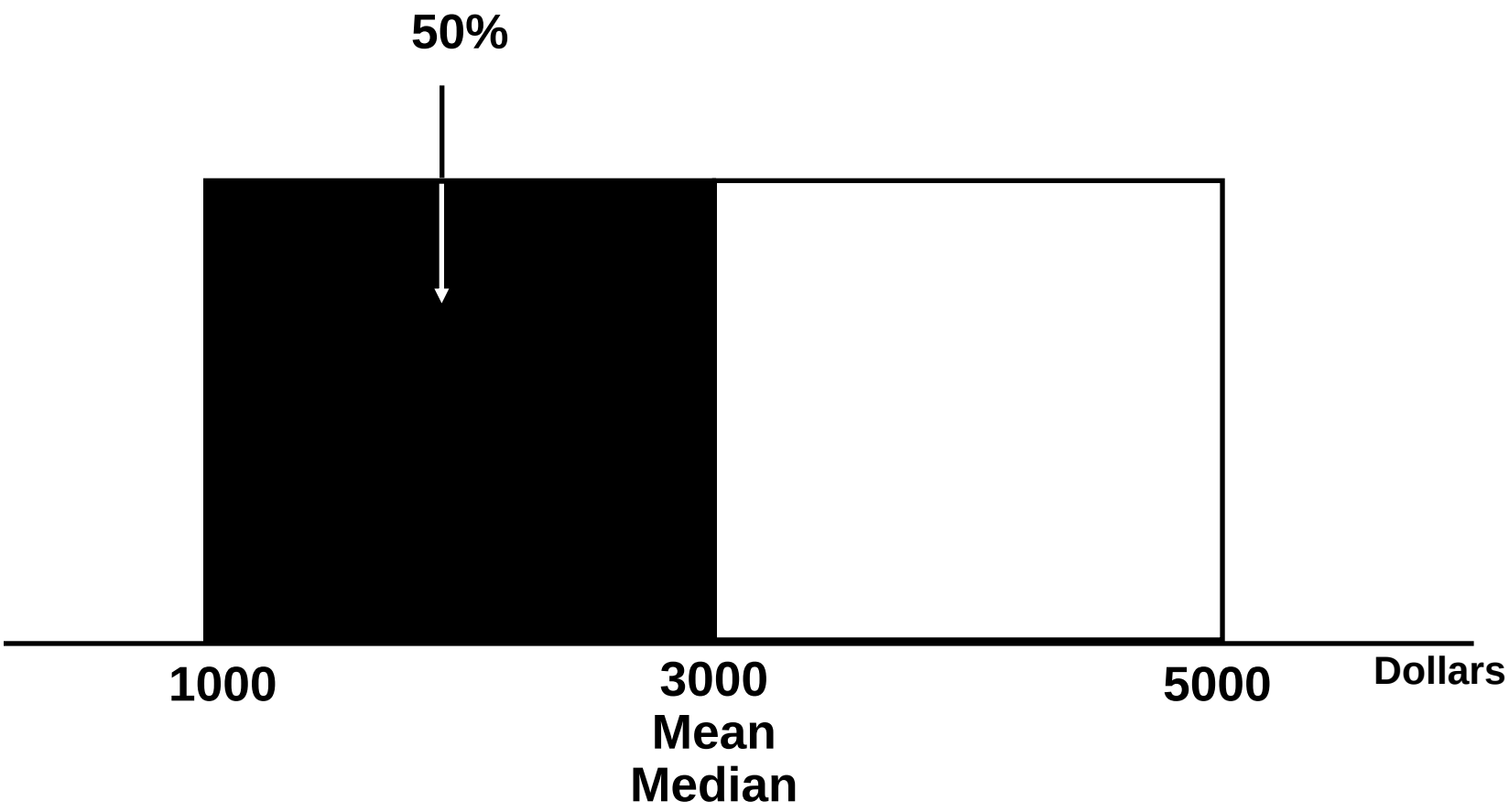


Statistics of Normal Distributions



$\sigma = 1000$

Statistics of Uniform Distributions



Summing Element Costs Statistically

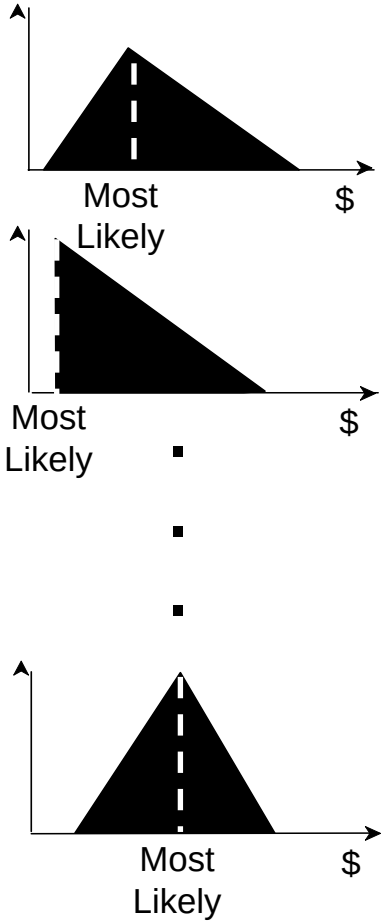
- **Central limit theorem of statistics: if number of *independent* WBS elements is "large," distribution of total cost is approximately normal**
- **Another statistical theorem: sum of WBS-element means = mean of total-program cost**
- **Therefore mean = median = mode for total-cost distribution**
  - **Total-cost mean = sum of WBS-element means**
  - **Total-cost median = sum of WBS-element means**
  - **Total-cost mode = sum of WBS-element means**

Summing Element Costs Statistically (Cont'd)

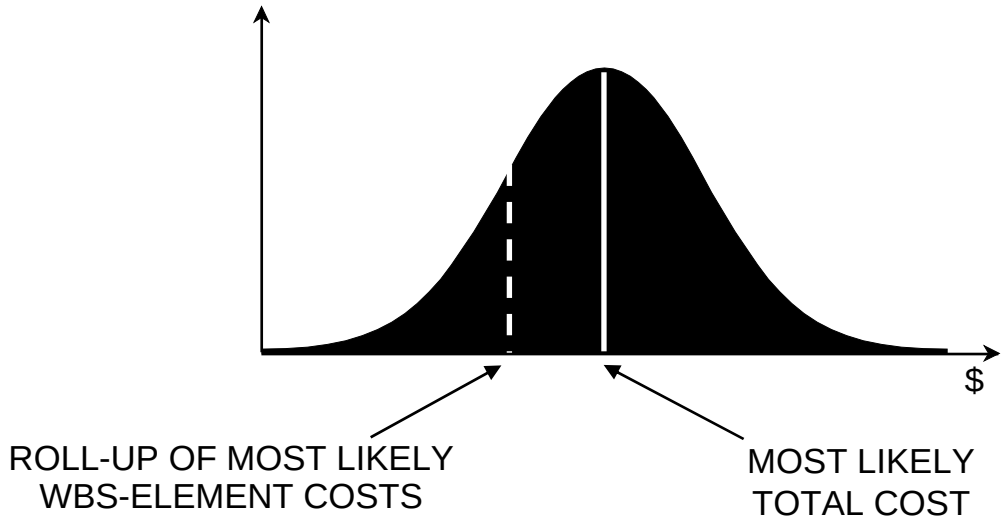
- **It inexorably follows that …**
  - **Total cost median > sum of WBS-element medians**
  - **Total cost mode > sum of WBS-element modes**

Central Limit Theorem in Pictures

WBS-ELEMENT TRIANGULAR COST DISTRIBUTIONS



MERGE WBS-ELEMENT COST DISTRIBUTIONS INTO TOTAL-COST NORMAL DISTRIBUTION



2nd Problem: The Fundamental Equation of Cost Estimating

$$1 + 1 = 3$$

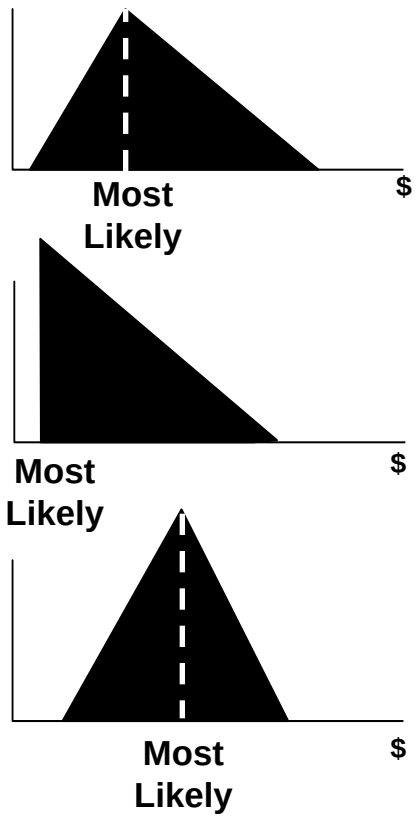
Is Naïve Roll-Up Procedure Valid?

No*

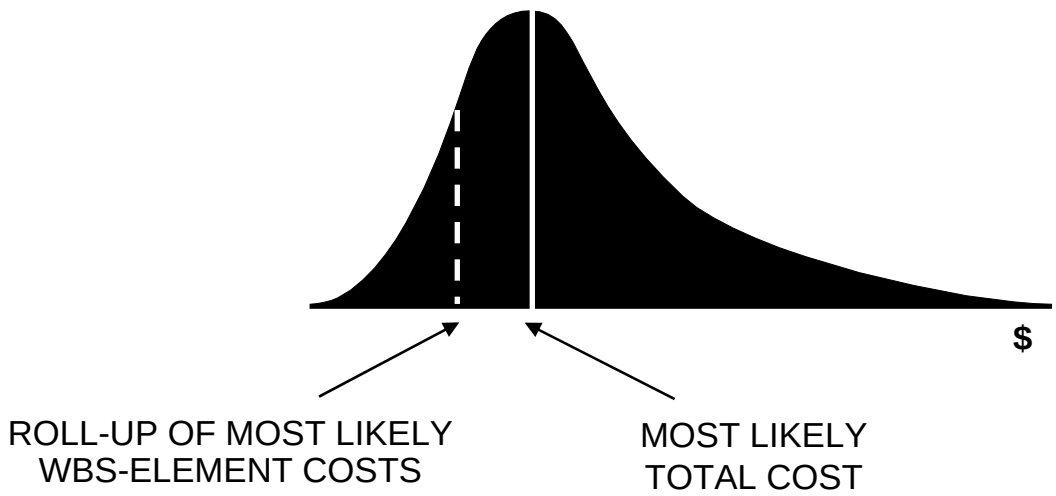
- **Well, hardly ever: <u>Only if</u> "best" means "mean" <u>or if</u> all WBS-element costs are Gaussian, uniform, or otherwise symmetric.**

When WBS Elements Are Few...

WBS-ELEMENT TRIANGULAR COST DISTRIBUTIONS



MERGE WBS-ELEMENT COST DISTRIBUTIONS INTO TOTAL-COST LOGNORMAL DISTRIBUTION



"Cost-Risk Analysis": A Procedure

- **Model WBS-element costs as uncertain quantities (i.e., random variables) that have probability distributions**
- **Combine WBS-element cost distributions statistically (either by simulation or analytic approximation) to generate cumulative distribution of total program cost**
- **Quantify confidence in anybody's "point" estimate of program cost or in budgeted funding**
- **Read off 70th percentile cost, 90th percentile cost, etc., from cumulative distribution to estimate additional amount of dollars needed to cover risk**

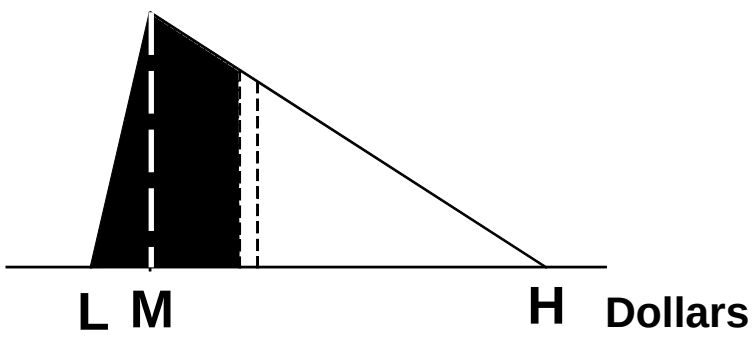
Example: Computer Simulation using Crystal Ball™ Software

- **High-level WBS:**
  - **1.1 System Engineering/Program Management**
  - **1.2 System Integration, Test and Evaluation**
  - **1.3 Software Development**
  - **1.4 Hardware Development**
  - **1.5 Prototype Development**
  - **1.6 Facilities Construction**
  - **1.7 Maintenance**

Example: L,M,H Inputs for Crystal Ball™ Application

- **Model each WBS-element cost as triangular distribution with the following parameters L, M, H:**

1.1: L = 20, M = 25, H = 40
1.2: L = 100, M = 130, H = 200
1.3: L = 30, M = 50, H = 90
1.4: L = 80, M = 100, H = 140
1.5: L = 100, M = 120, H = 150
1.6: L = 10, M = 15, H = 30
1.7: L = 90, M = 100, H = 170



- **Note: sum of most likely costs = 540 (Remember this for later!)**

Example: Correlation Inputs for Crystal Ball™ Application

- **Pairwise Correlations as Follows:**

	1.1	1.2	1.3	1.4	1.5	1.6	1.7
1.1:	1.0	0.4	0.4	0.4	0.4	0.4	0.4
1.2:	x	1.0	0.5	0.5	0.5	0.7	0.3
1.3:	x	x	1.0	0.7	0.7	0.7	0.7
1.4:	x	x	x	1.0	0.4	0.4	0.4
1.5:	x	x	x	x	1.0	0.7	0.7
1.6:	x	x	x	x	x	1.0	0.6
1.7:	x	x	x	x	x	x	1.0

What a Cost Estimate Looks Like (Reprise)

(Crystal Ball® Outputs)

Percentile	Value
10%	516.81
20%	538.98
30%	557.85
40%	575.48
50%	592.72
60%	609.70
70%	629.19
80%	650.97
90%	683.01

Statistics	Value
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Range Minimum	450.19
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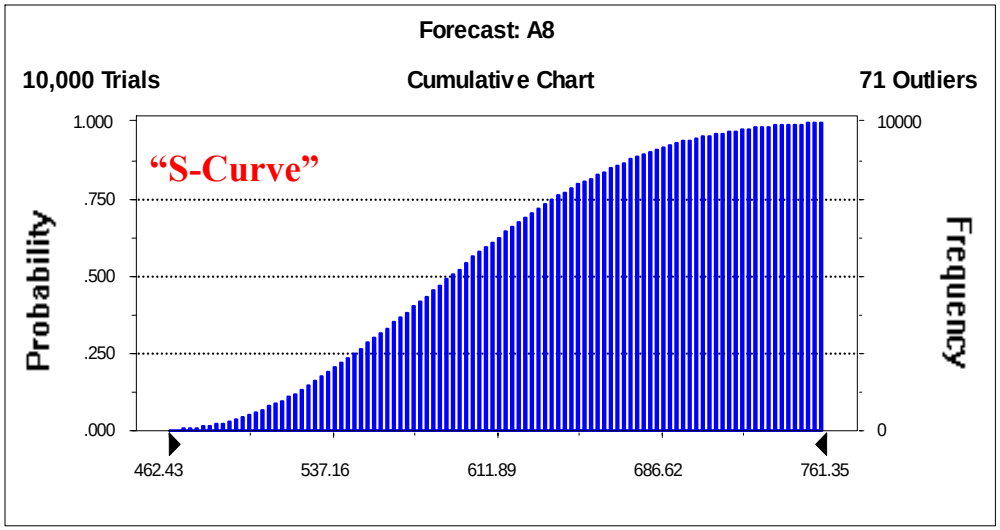
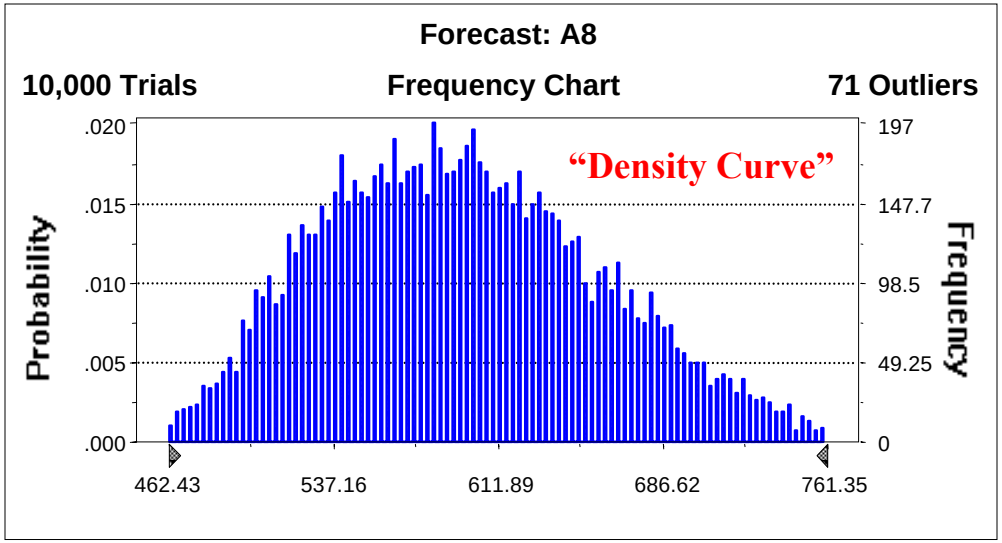
Recall: Sum of Most Likely Costs = 540





The Statistical Nature of Risk

- We must treat additional risk-induced costs as random variables with probability distributions because not all risks will come to pass
- A triangular probability distribution can be established for each WBS element as follows
- We discuss later how these distributions can be determined using the Earned Value data

The Statistical Nature of Risk (Cont'd)

- **Neither L, M, nor H will be the exact cost of the WBS element to which they correspond**
  - **Uncertainty in how project development will actually proceed makes it impossible to forecast WBS-element costs with high confidence**
  - **Statistical summation of element costs reflects this uncertainty and allow us to obtain a better understanding of project total cost that we have of any particular WBS element's cost**

Tools to Use

- **Simulation packages**
  - **Crystal Ball**
  - **@RISK**
  - **RISK+ (for MS Project Schedule Analysis)**
- **Analytical tool**
  - **Formal Risk Assessment of Systems Cost (FRISK)**

Summary

- **Do not sum "most likely" cost estimates, because:**
  - **The number you get does not mean what you think it means**
  - **In fact, nobody knows what it means, except that it almost certainly underestimates the most likely total cost**
- **Costs are random variables, not deterministic numbers, with cost risk (uncertainty) due to …**
  - **Technical, programmatic difficulties and problems**
  - **Statistical estimating error**
  - **Characteristics of cost probability distributions estimated from information provided in project's risk-management plan**

Summary (Cont'd)

- **Cost-risk analysis helps project managers understand likelihoods of incurring cost overruns of various magnitudes, so they can take appropriate action**

Be in the business of estimating probabilities (levels of confidence), not dollar cost values

Agenda

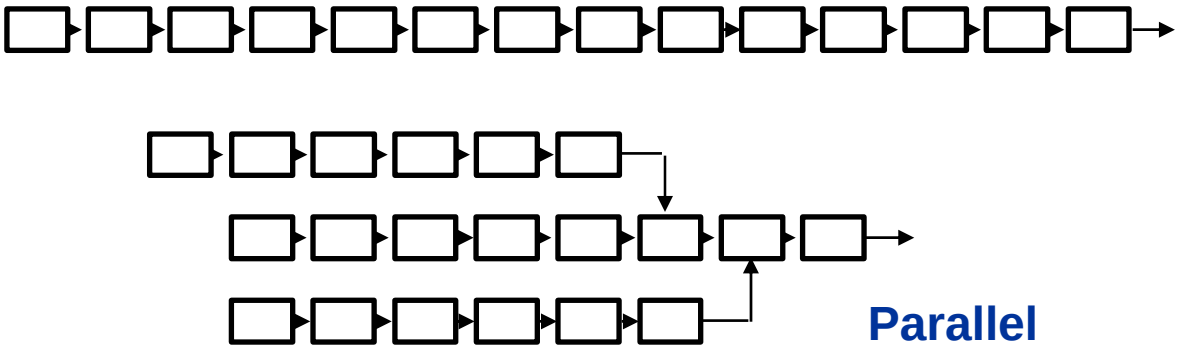
- 9:00 – 9:15 Introductions & Overview - Lehman
- 9:15 – 10:15 Intro to EVM/Evolving Policy – Driessnack
- 10:15 – 10:45 Break
- 10:45 – 11:15 EVM/Policy continued - Driessnack
- 11:15 – 12:00 1st Soupçon of Statistics – Dr Hulkower
- 12:00 – 1:15 Lunch (On Your Own)
- 1:15 – 2:00 Scheduling and Risk Analysis - Driessnack
- 2:00 – 2:30 2nd Soupçon of Statistics – Dr Hulkower
- 2:30 – 3:00 Break
- 3:00 – 3:30 Estimates part 1 - Driessnack
- 3:30 - 4:00 Estimates part 2 - Dr Hulkower

Ways Of Arranging Activities In A Network

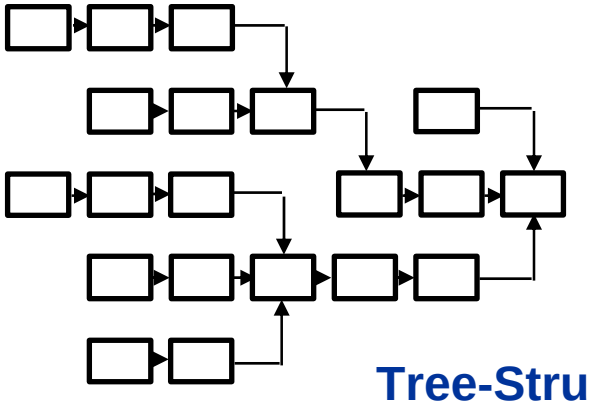
- Serial Arrangement: Two Activities are “in Serial” if Each is a Predecessor or a Successor of the Other
- Parallel Arrangement: Two Activities are “in Parallel” if Neither is a Predecessor or a Successor of the Other
- Tree Structure: A Mixture of Serial and Parallel Activities
- Feedback Loop: A Sequence of Activities that Contains at Least Two Activities that are both Predecessors and Successors of Each Other

Types Of Networks

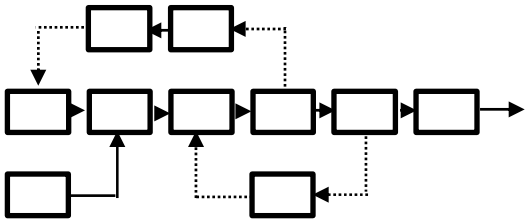
Serial



Parallel



Tree-Structured



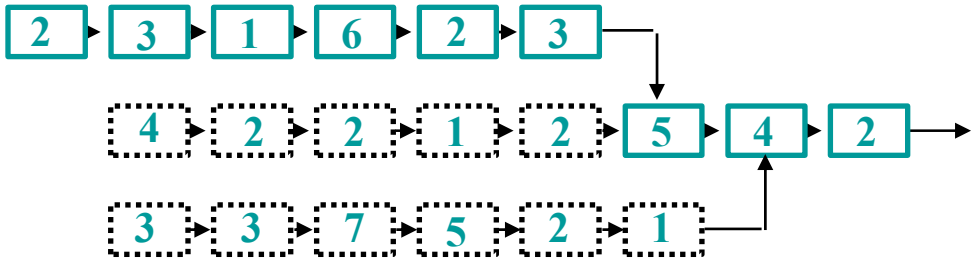
Feedback Loop (Rework)

Serial Network

- Number in Box Indicates Number of Days Allocated to Task Represented by Box
- A Serial Network's Critical Path Passes Through All Boxes, and its Duration is the Sum of the Durations of the Individual Activities in the Serial Network
- Critical Path, Consisting of Boxes Outlined in Blue Lines, has Total Duration = 46 days
- 3 → 1 → 6 → 2 → 3 → 4 → 2 → 2 → 1 → 8 → 3 → 4 → 5 → 2 →

Parallel Network

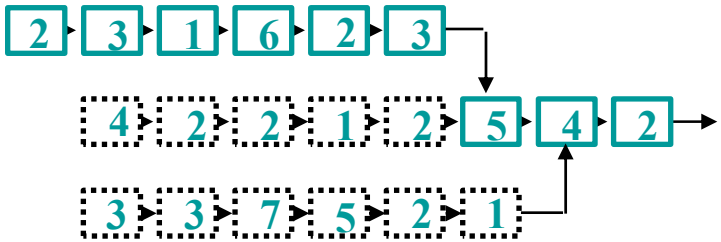
- Numbers in Boxes Indicate Number of Days Allocated to Task Represented by Box
- Parallel Network's Critical Path Passes Through Those Boxes whose Combined Duration is the Longest Possible through the Network
- Critical Path, Consisting of Boxes Outlined in Blue Lines, has Total Duration = 28 Days
- Sequences of Boxes Outlined in Dotted Black Lines Have "Slack Time", 6 Days and 1 Day, Respectively



Why Schedule Analysis Differs From Cost Analysis

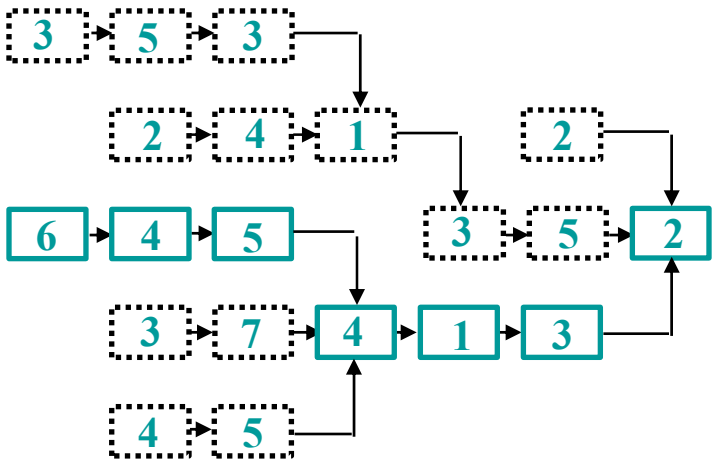
- The Work- Breakdown Structure is a “Linear” List, and Program Cost is Calculated by Adding Together the Costs of All Items on That List
- The Schedule Network (Unless it is Entirely Serial) is Not Linear, and Therefore Program Duration Cannot be Calculated by Adding Together the Durations of All Activities in the Network

0.0	TOTAL BRILLIANT EYES PROGRAM
1.0	SPACE BRILLIANT EYES SYSTEM
1.1	System-Level Costs
1.2	Space Vehicle (SV) Segment
1.2.1	SV Program Level
1.2.2	Space Vehicle Prime Mission Equipment
1.2.2.1	Space Software
1.2.2.2	Space Vehicle
1.2.2.2.1	Space Vehicle IA&T
1.2.2.2.2	Sensor Payload
1.2.2.2.3	Insertion Vehicle
1.2.2.2.4	Survivability
1.2.3	Prototype Lot
1.2.4	Spare Parts
1.2.5	Technology and Producibility
1.2.6	Aerospace Ground Equipment
1.2.7	Launch Support
1.3	Engineering Change Orders (ECOs)
1.4	Other Government Costs
1.5	Risk



Tree-Structured Network

- Numbers in Boxes Indicate Number of Days Allocated to Task Represented by Box
- Critical Path Passes Through Those Boxes whose Combined Duration is the Longest Possible through the Network
- Critical Path, Consisting of Boxes Outlined in Blue Lines, has Total Duration = 25 Days
- Sequences of Boxes Outlined in Dotted Black Lines Have “Slack Time”, 3 Days, 5 Days, 21 Days, 5 Days and 6 Days, Respectively



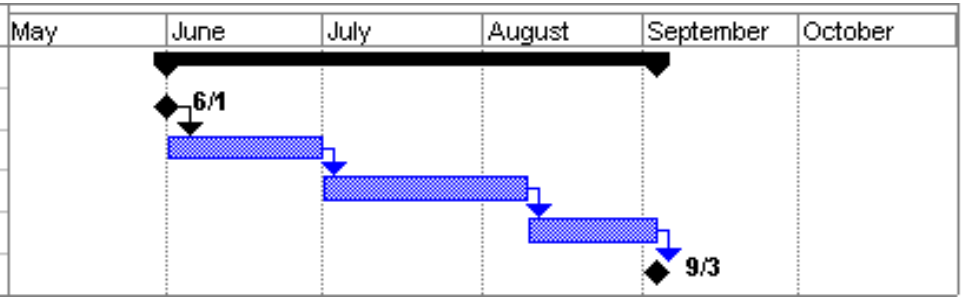
Network Schedule Analysis

- Understand Logical Flow of How Activities Lead to Completion of Program
  - Define How Activities are Linked
  - Determine Order in which Activities Must be Done
  - Identify Milestone Activities and “Choke Points”
- Estimate Activity Durations
- Estimate Program Completion Time
  - Construct Critical Path to Estimate when Program Can be Completed
  - Compare the Estimate with Program’s Required Completion Time

A Simple Schedule

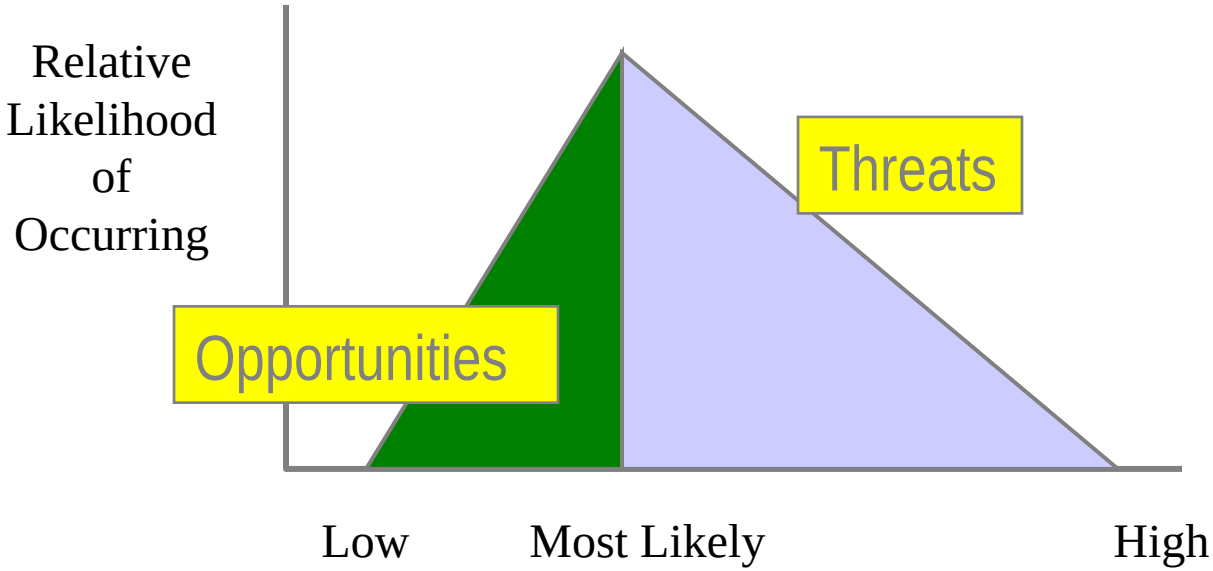
- **Basic schedule…start 1 Jun with finish on Sept 3rd**
  - **3 activities with duration**
  - **Success oriented…no failure planned**
  - **Scheduled the way that most of us schedule**

ID	Task Name	Duration	Start	Finish
1	**Project**	**95 days**	**Sat 6/1/02**	**Tue 9/3/02**
2	Start	0 days	Sat 6/1/02	Sat 6/1/02
3	Design Unit	30 days	Sat 6/1/02	Sun 6/30/02
4	Build Unit	40 days	Mon 7/1/02	Fri 8/9/02
5	Test Unit	25 days	Sat 8/10/02	Tue 9/3/02
6	Finish	0 days	Tue 9/3/02	Tue 9/3/02



Schedule

Triangular Probability Distribution



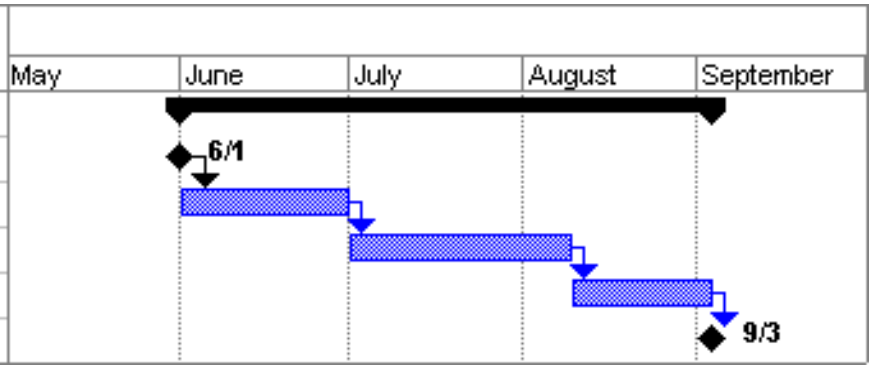
ID	Task Name	Opt Duration	Exp Dur	Pess Duration
1	**Project**	**75 days**	**95 days**	**145 days**
2	Start	0 days	0 days	0 days
3	Design Unit	20 days	30 days	45 days
4	Build Unit	35 days	40 days	50 days
5	Test Unit	20 days	25 days	50 days
6	Finish	0 days	0 days	0 days

A Simple PERT Schedule

- **Add an Optimistic, Pessimistic and Most Likely Duration**
  - Project end date is 8/14 – 10/23
  - Still expect to end on 9/3

ID	Task Name	Opt Duration	Opt Start	Opt Finish	Exp Dur	Exp Start	Exp Finish
1	**Project**	**75 days**	**Sat 6/1/02**	**Wed 8/14/02**	**95 days**	**Sat 6/1/02**	**Tue 9/3/02**
2	Start	0 days	Sat 6/1/02	Sat 6/1/02	0 days	Sat 6/1/02	Sat 6/1/02
3	Design Unit	20 days	Sat 6/1/02	Thu 6/20/02	30 days	Sat 6/1/02	Sun 6/30/02
4	Build Unit	35 days	Fri 6/21/02	Thu 7/25/02	40 days	Mon 7/1/02	Fri 8/9/02
5	Test Unit	20 days	Fri 7/26/02	Wed 8/14/02	25 days	Sat 8/10/02	Tue 9/3/02
6	Finish	0 days	Wed 8/14/02	Wed 8/14/02	0 days	Tue 9/3/02	Tue 9/3/02

Pess Duration	Pess Start	Pess Finish
145 days	**Sat 6/1/02**	**Wed 10/23/02**
0 days	Sat 6/1/02	Sat 6/1/02
45 days	Sat 6/1/02	Mon 7/15/02
50 days	Tue 7/16/02	Tue 9/3/02
50 days	Wed 9/4/02	Wed 10/23/02
0 days	Wed 10/23/02	Wed 10/23/02



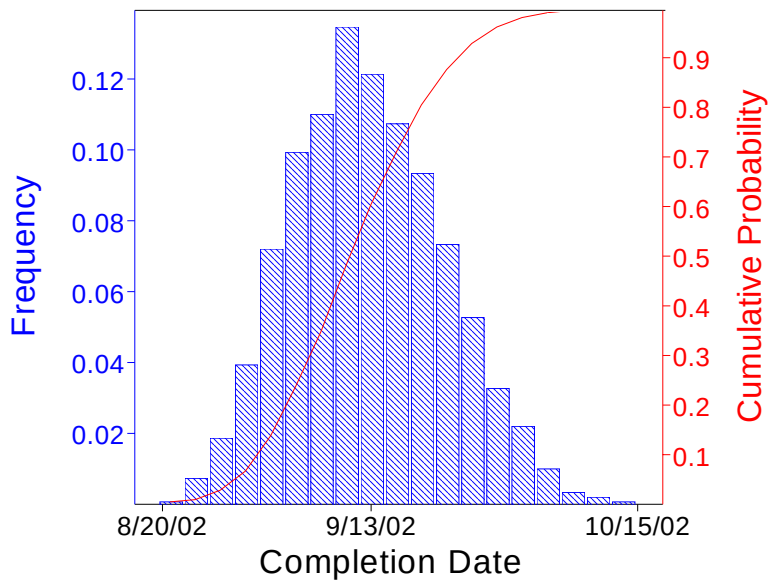
Schedule

Monte Carlo provides range

- 3 Sept less than 15% likely …

Date: 10/25/2001 3:42:21 PM
Samples: 5000
Unique ID: 2
Name: Project

Completion Std Deviation: 8.98 d
Confidence Interval: 0.25 d
Each bar represents 3 d



Completion Probability Table

Prob	Date	Prob	Date
0.05	8/31/02	0.55	9/14/02
0.10	9/2/02	0.60	9/15/02
0.15	9/4/02	0.65	9/17/02
0.20	9/5/02	0.70	9/18/02
0.25	9/7/02	0.75	9/20/02
0.30	9/8/02	0.80	9/21/02
0.35	9/10/02	0.85	9/23/02
0.40	9/11/02	0.90	9/26/02
0.45	9/12/02	0.95	9/29/02
0.50	9/13/02	1.00	10/15/02

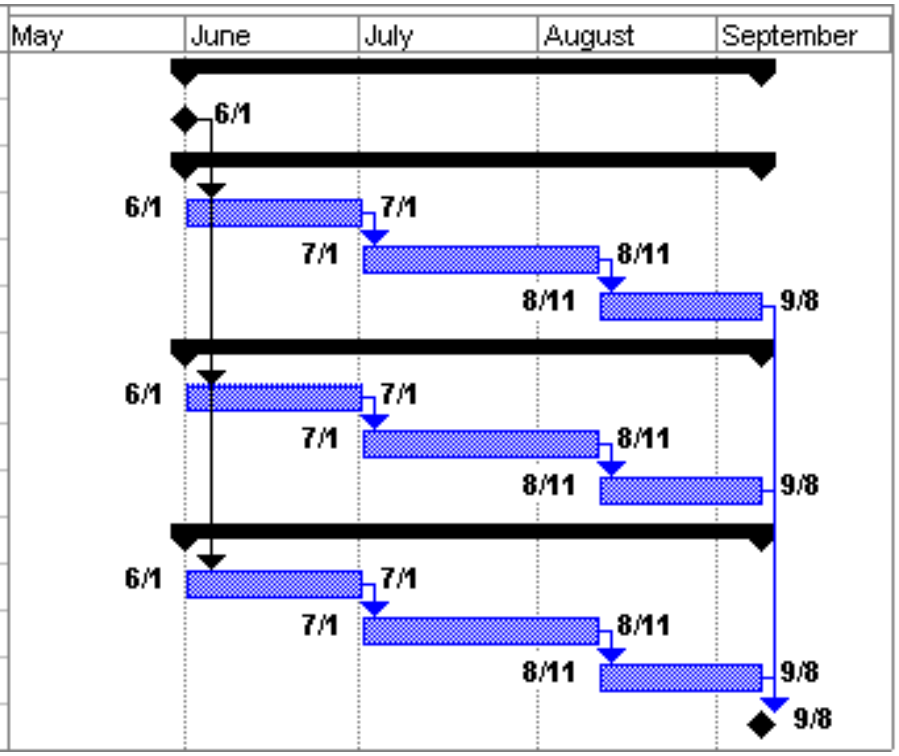
Nominal 9/3 Finish Date

Schedule slides modified from Dr David Hulett (Risk CoP)

Schedule … parallel paths

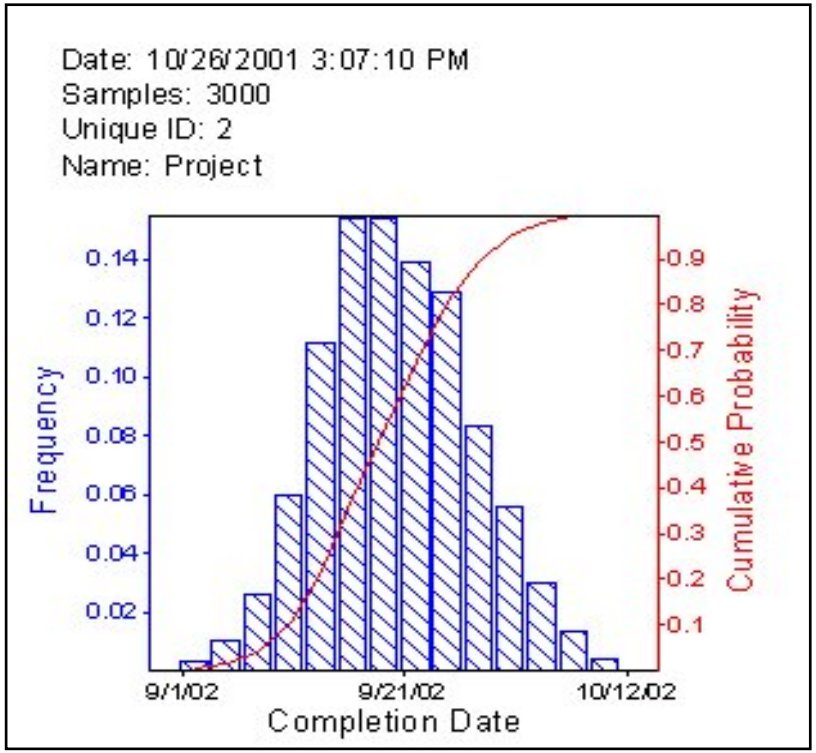
- **What happens with three similar paths**
  - **Similar activities**
    - **Design, Build, Test**

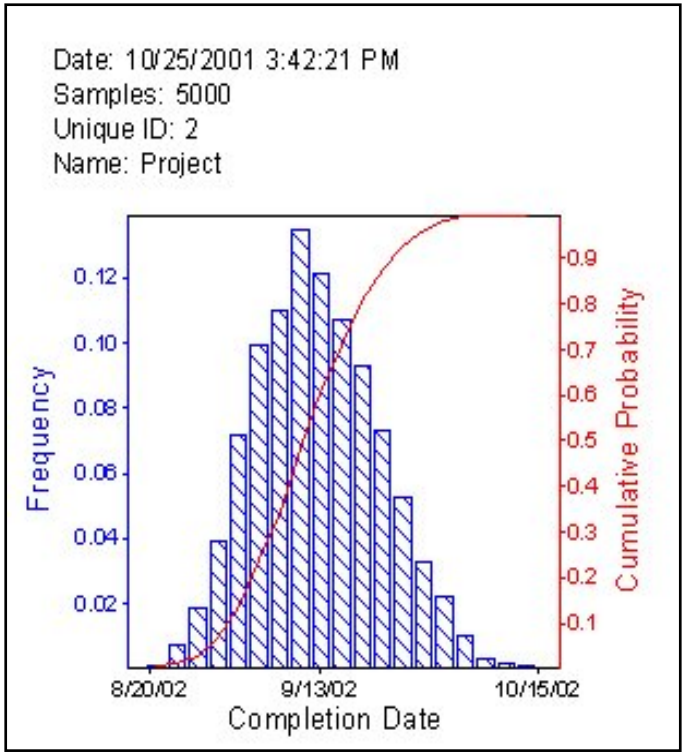
ID	Task Name	Exp Dur	Exp Start	Exp Finish
1	**Project**	**95 days**	**Sat 6/1/02**	**Tue 9/3/02**
2	Start	0 days	Sat 6/1/02	Sat 6/1/02
3	**Unit 1**	**0 days**	**NA**	**NA**
4	Design Unit 1	30 days	Sat 6/1/02	Sun 6/30/02
5	Build Unit 1	40 days	Mon 7/1/02	Fri 8/9/02
6	Test Unit 1	25 days	Sat 8/10/02	Tue 9/3/02
7	**Unit 2**	**0 days**	**NA**	**NA**
8	Design Unit 2	30 days	Sat 6/1/02	Sun 6/30/02
9	Build Unit 2	40 days	Mon 7/1/02	Fri 8/9/02
10	Test Unit 2	25 days	Sat 8/10/02	Tue 9/3/02
11	**Unit 3**	**0 days**	**NA**	**NA**
12	Design Unit 3	30 days	Sat 6/1/02	Sun 6/30/02
13	Build Unit 3	40 days	Mon 7/1/02	Fri 8/9/02
14	Test Unit 3	25 days	Sat 8/10/02	Tue 9/3/02
15	Finish	0 days	Tue 9/3/02	Tue 9/3/02



More schedule paths changes the risk

- **Three paths tighten range, moves 50% a week!**



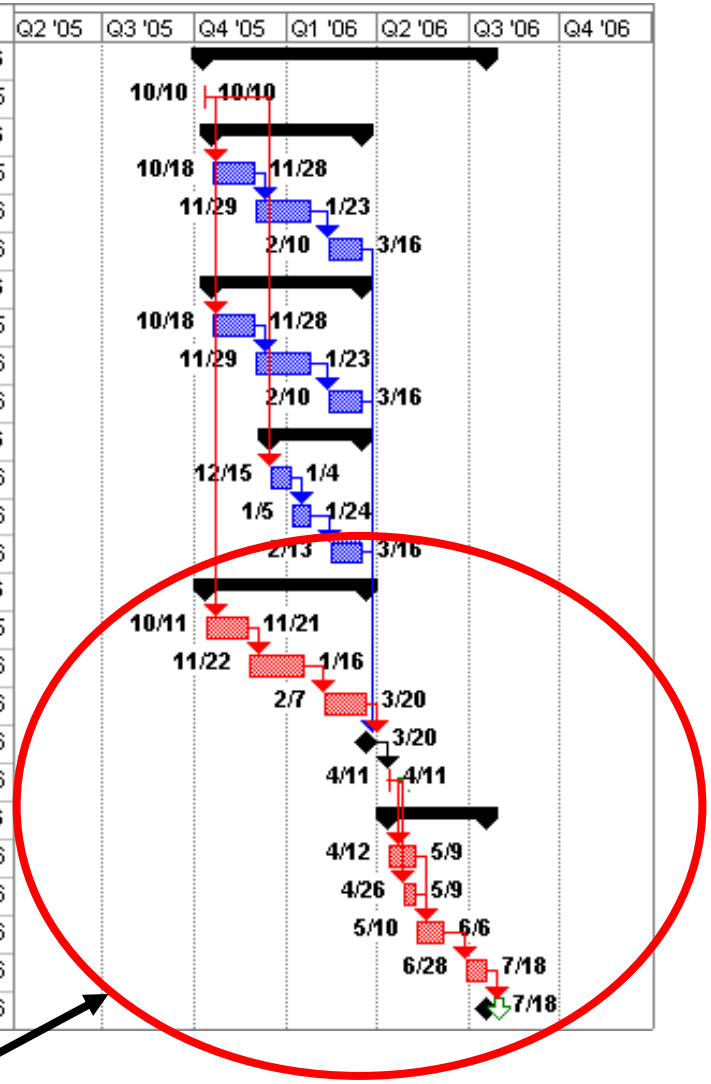


Three Path Schedule

One Path Schedule

Schedule Min/Max Dates
Critical Path Shown

ID	Task Name	Opt Duration	Exp Duration	Pess Duration	Finish
1	**Project**	**0 days**	**0 days**	**0 days**	**Tue 7/18/06**
2	Release Work Order	0 days	0 days	0 days	Mon 10/10/05
3	**Unit A Control Accoun**	**0 days**	**0 days**	**0 days**	**Thu 3/16/06**
4	Design Unit A	25 days	30 days	55 days	Mon 11/28/05
5	Builid Unit A	35 days	40 days	65 days	Mon 1/23/06
6	Test Unit A	20 days	25 days	50 days	Thu 3/16/06
7	**Unit B Control Accoun**	**0 days**	**0 days**	**0 days**	**Thu 3/16/06**
8	Design Unit B	20 days	30 days	35 days	Mon 11/28/05
9	Builid Unit B	30 days	40 days	45 days	Mon 1/23/06
10	Test Unit B	15 days	25 days	30 days	Thu 3/16/06
11	**Unit C Control Accoun**	**0 days**	**0 days**	**0 days**	**Thu 3/16/06**
12	Design Unit C	12 days	15 days	30 days	Wed 1/4/06
13	Builid Unit C	12 days	14 days	28 days	Tue 1/24/06
14	Test Unit C	22 days	24 days	48 days	Thu 3/16/06
15	**Unit D control Account**	**0 days**	**0 days**	**0 days**	**Mon 3/20/06**
16	Design Unit D	15 days	30 days	35 days	Mon 11/21/05
17	Builid Unit D	20 days	40 days	45 days	Mon 1/16/06
18	Test Unit D	15 days	30 days	35 days	Mon 3/20/06
19	Customer Review o1	10 days	15 days	30 days	Mon 3/20/06
20	Customer Review before	0 days	0 days	0 days	Tue 4/11/06
21	**Integration**	**0 days**	**0 days**	**0 days**	**Tue 7/18/06**
22	Integrate Units A anc	15 days	20 days	25 days	Tue 5/9/06
23	Integrate Units B anc	8 days	10 days	30 days	Tue 5/9/06
24	Integrate System	15 days	20 days	40 days	Tue 6/6/06
25	Test System	10 days	15 days	25 days	Tue 7/18/06
26	Delivery to Customer	0 days	0 days	0 days	Tue 7/18/06



Static critical path

Schedule Min/Max Dates

Identification of % on critical path

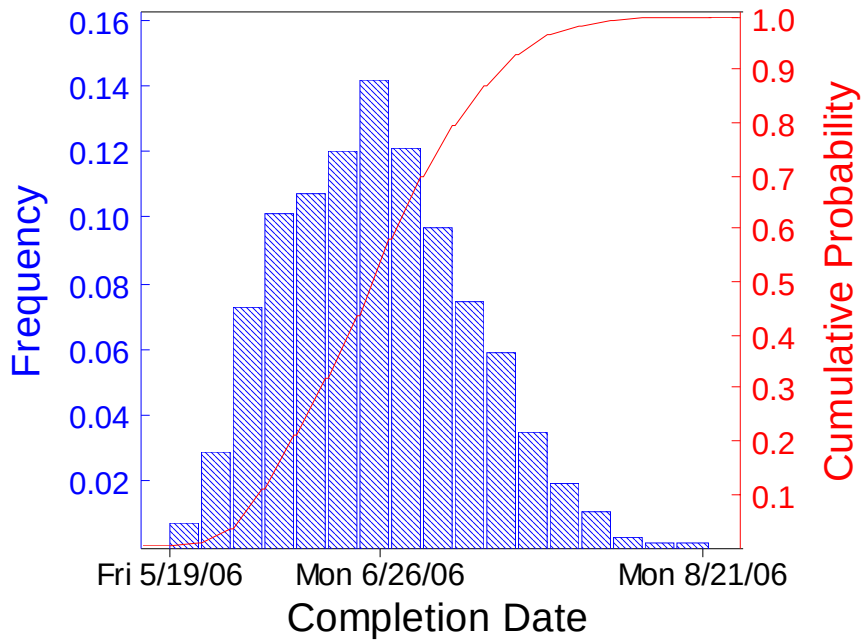
ID	Task Name	Duration	Finish	Min Rdur	ML Rdur	Max Rdur
1	**Project**	**172 days**	**Tue 6/6/06**	**0 days**	**0 days**	**0 days**
2	Release Work Order	1 day	Mon 10/10/05	0 days	0 days	0 days
3	**Unit A Control Account (Risk)**	**95 days**	**Mon 2/20/06**	**0 days**	**0 days**	**0 days**
4	Design Unit A	30 days	Mon 11/21/05	25 days	30 days	55 days
5	Builid Unit A	40 days	Mon 1/16/06	35 days	40 days	65 days
6	Test Unit A	25 days	Mon 2/20/06	20 days	25 days	50 days
7	**Unit B Control Account (Opportunity)**	**95 days**	**Mon 2/20/06**	**0 days**	**0 days**	**0 days**
8	Design Unit B	30 days	Mon 11/21/05	20 days	30 days	35 days
9	Builid Unit B	40 days	Mon 1/16/06	30 days	40 days	45 days
10	Test Unit B	25 days	Mon 2/20/06	15 days	25 days	30 days
11	**Unit C Control Account (Risk short)**	**53 days**	**Thu 12/22/05**	**0 days**	**0 days**	**0 days**
12	Design Unit C	15 days	Mon 10/31/05	12 days	15 days	30 days
13	Builid Unit C	14 days	Fri 11/18/05	12 days	14 days	28 days
14	Test Unit C	24 days	Thu 12/22/05	22 days	24 days	48 days
15	**Unit D control Account (Opp Long)**	**115 days**	**Mon 3/20/06**	**0 days**	**0 days**	**0 days**
16	Design Unit D	30 days	Mon 11/21/05	15 days	30 days	35 days
17	Builid Unit D	40 days	Mon 1/16/06	20 days	40 days	45 days
18	Test Unit D	30 days	Mon 2/27/06	15 days	30 days	35 days
19	Customer Review of Test Data	15 days	Mon 3/20/06	10 days	15 days	30 days
20	Customer Review before Integration	1 day	Tue 3/21/06	0 days	0 days	0 days
21	**Integration**	**55 days**	**Tue 6/6/06**	**0 days**	**0 days**	**0 days**
22	Integrate Units A and C	20 days	Tue 4/18/06	15 days	20 days	25 days
23	Integrate Units B and C	10 days	Tue 4/4/06	8 days	10 days	30 days
24	Integrate System	20 days	Tue 5/16/06	15 days	20 days	40 days
25	Test System	15 days	Tue 6/6/06	10 days	15 days	25 days
26	Delivery to Customer	0 days	Tue 6/6/06	0 days	0 days	0 days

Critical path on Unit A 97% of the time

Risk + Analysis
Impact of uncertainty in durations

Date: 10/8/2005 4:04:42 PM
Samples: 2500
Unique ID: 32
Name: Delivery to Customer

Completion Std Deviation: 11.42 days
95% Confidence Interval: 0.45 days
Each bar represents 4 days



Completion Probability Table

Prob	Date	Prob	Date
0.05	Thu 6/1/06	0.55	Tue 6/27/06
0.10	Mon 6/5/06	0.60	Wed 6/28/06
0.15	Wed 6/7/06	0.65	Fri 6/30/06
0.20	Fri 6/9/06	0.70	Tue 7/4/06
0.25	Tue 6/13/06	0.75	Thu 7/6/06
0.30	Thu 6/15/06	0.80	Mon 7/10/06
0.35	Mon 6/19/06	0.85	Wed 7/12/06
0.40	Tue 6/20/06	0.90	Mon 7/17/06
0.45	Thu 6/22/06	0.95	Mon 7/24/06
0.50	Fri 6/23/06	1.00	Mon 8/21/06

Schedule data is 6/6/2006 – only 10-15% chance
75% chance estimated to be 1 Month slip – 7/6/2006

Sensitivity Analysis

ID	Task Name	Early Finish	Late Finish	Range
24	Integrate System	Fri 5/26/06	Fri 6/30/06	25 days
4	Design Unit A	Fri 6/2/06	Fri 6/30/06	20 days
5	Builid Unit A	Fri 6/2/06	Fri 6/30/06	20 days
6	Test Unit A	Fri 6/2/06	Fri 6/30/06	20 days
19	Customer Review ot	Fri 5/26/06	Fri 6/23/06	20 days
25	Test System	Fri 5/26/06	Fri 6/16/06	15 days
16	Design Unit D	Fri 5/26/06	Fri 6/9/06	10 days
17	Builid Unit D	Fri 5/26/06	Fri 6/9/06	10 days
18	Test Unit D	Fri 5/26/06	Fri 6/9/06	10 days
22	Integrate Units A anc	Fri 5/26/06	Fri 6/9/06	10 days
23	Integrate Units B anc	Fri 6/2/06	Fri 6/16/06	10 days
2	Release Work Order	Fri 6/2/06	Fri 6/2/06	0 days
8	Design Unit B	Fri 6/2/06	Fri 6/2/06	0 days
9	Builid Unit B	Fri 6/2/06	Fri 6/2/06	0 days
10	Test Unit B	Fri 6/2/06	Fri 6/2/06	0 days
12	Design Unit C	Fri 6/2/06	Fri 6/2/06	0 days
13	Builid Unit C	Fri 6/2/06	Fri 6/2/06	0 days
14	Test Unit C	Fri 6/2/06	Fri 6/2/06	0 days
20	Customer Review before	Fri 6/2/06	Fri 6/2/06	0 days

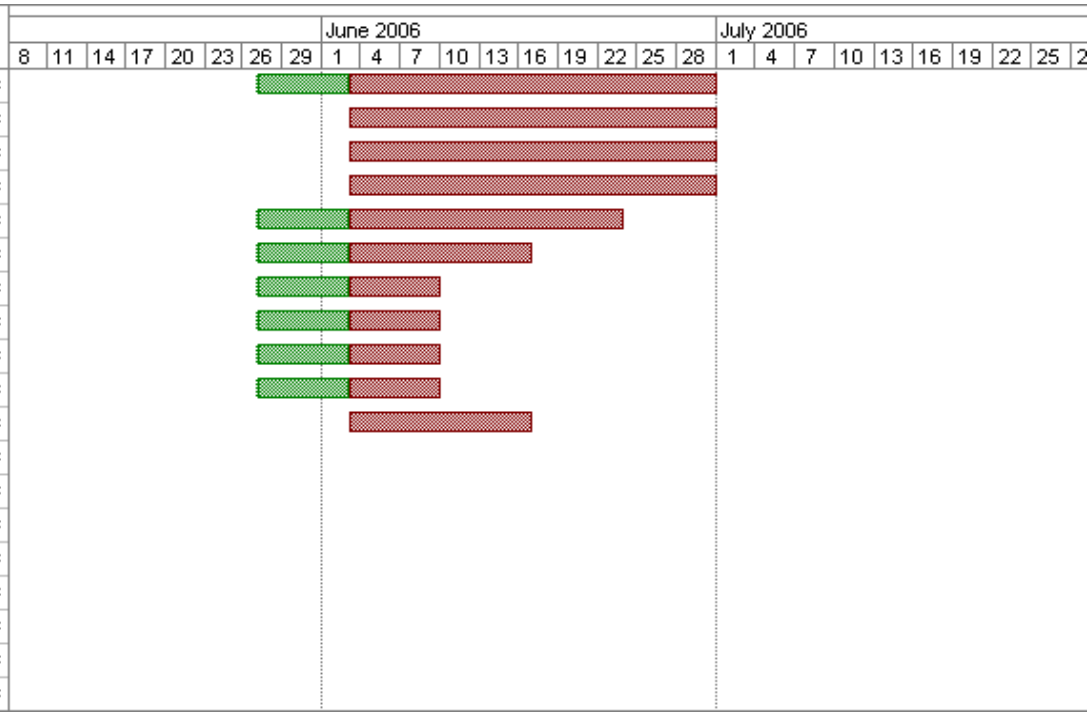
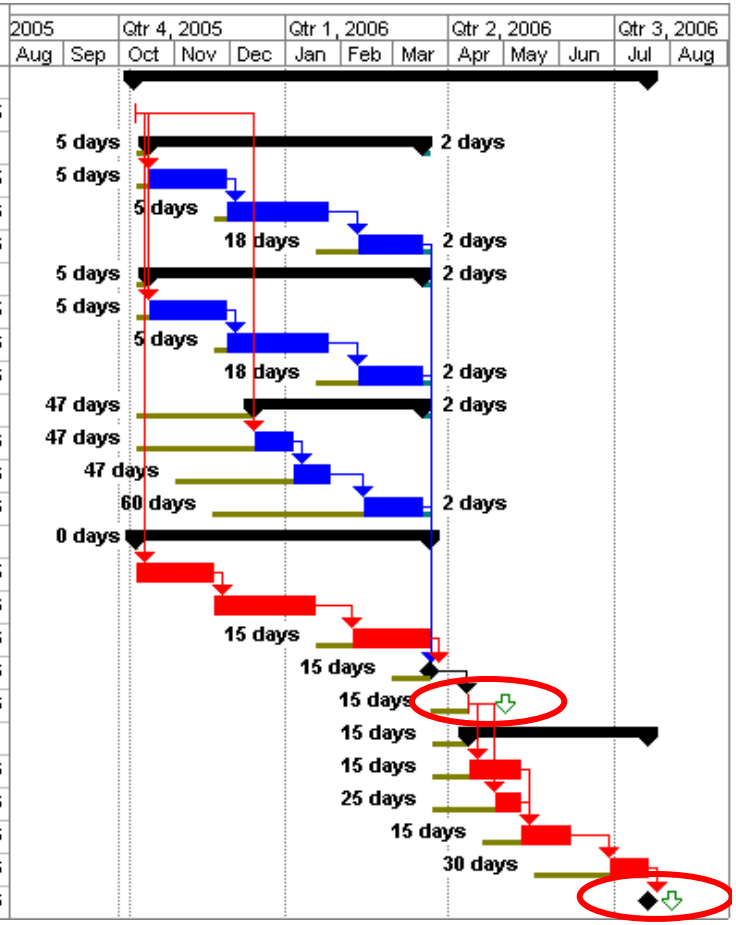


Chart indicates the drives in the schedule.

- Unit A as riskier activities rank high
- Unit D on critical path and opportunities are significant

Schedule with Lags
Adjusted to meet Deadlines

ID		Task Name	Duration	Predecessors	Start	Finish
1		**Project**	**202 days**		**Mon 10/10/05**	**Tue 7/18/06**
2		Release Work Order	1 day		Mon 10/10/05	Mon 10/10/05
3		**Unit A Control Account (Risk)**	**108 days**		**Tue 10/18/05**	**Thu 3/16/06**
4		Design Unit A	30 days	2FS+5 days	Tue 10/18/05	Mon 11/28/05
5		Builid Unit A	40 days	4	Tue 11/29/05	Mon 1/23/06
6		Test Unit A	25 days	5FS+13 days	Fri 2/10/06	Thu 3/16/06
7		**Unit B Control Account (Opportunity)**	**108 days**		**Tue 10/18/05**	**Thu 3/16/06**
8		Design Unit B	30 days	2FS+5 days	Tue 10/18/05	Mon 11/28/05
9		Builid Unit B	40 days	8	Tue 11/29/05	Mon 1/23/06
10		Test Unit B	25 days	9FS+13 days	Fri 2/10/06	Thu 3/16/06
11		**Unit C Control Account (Risk short)**	**66 days**		**Thu 12/15/05**	**Thu 3/16/06**
12		Design Unit C	15 days	2FS+47 days	Thu 12/15/05	Wed 1/4/06
13		Builid Unit C	14 days	12	Thu 1/5/06	Tue 1/24/06
14		Test Unit C	24 days	13FS+13 days	Mon 2/13/06	Thu 3/16/06
15		**Unit D control Account (Opp Long)**	**115 days**		**Tue 10/11/05**	**Mon 3/20/06**
16		Design Unit D	30 days	2	Tue 10/11/05	Mon 11/21/05
17		Builid Unit D	40 days	16	Tue 11/22/05	Mon 1/16/06
18		Test Unit D	30 days	17FS+15 days	Tue 2/7/06	Mon 3/20/06
19		Customer Review of Test Data	0 days	6,10,14,18	Mon 3/20/06	Mon 3/20/06
20		Customer Review before Integration	1 day	9FS+15 days	Tue 4/11/06	Tue 4/11/06
21		**Integration**	**70 days**		**Wed 4/12/06**	**Tue 7/18/06**
22		Integrate Units A and C	20 days	20	Wed 4/12/06	Tue 5/9/06
23		Integrate Units B and C	10 days	20FS+10 days	Wed 4/26/06	Tue 5/9/06
24		Integrate System	20 days	22,23	Wed 5/10/06	Tue 6/6/06
25		Test System	15 days	24FS+15 days	Wed 6/28/06	Tue 7/18/06
26		Delivery to Customer	0 days	25	Tue 7/18/06	Tue 7/18/06



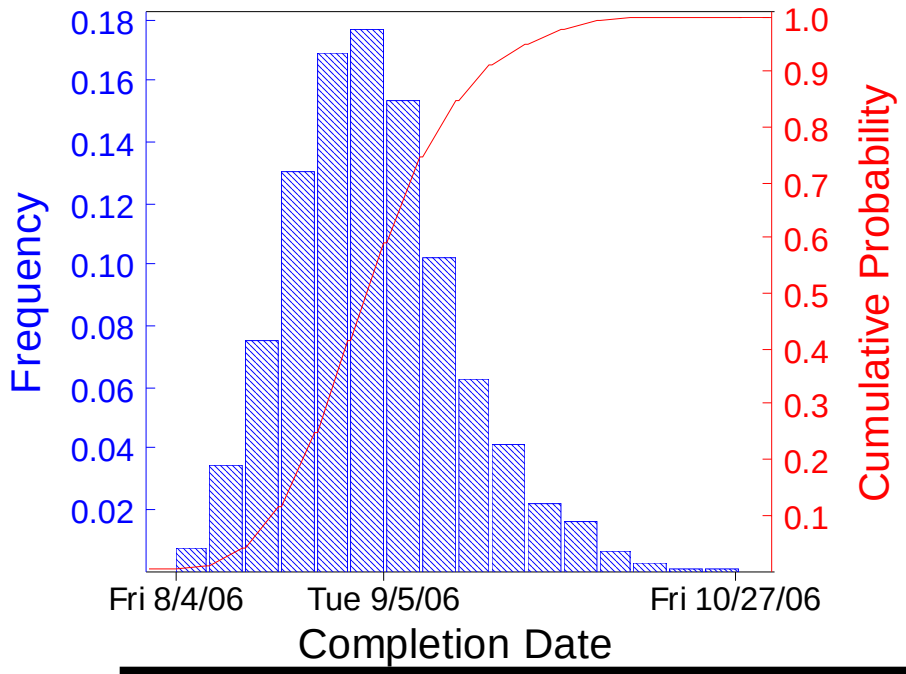
Management Lags added to align schedule to Deadline

Line 19 dropped to zero days, 15 day lag added to Line 20

Risk + Analysis
Impact of Lag on estimate

Date: 10/8/2005 4:23:42 PM
Samples: 2500
Unique ID: 32
Name: Delivery to Customer

Completion Std Deviation: 9.36 days
95% Confidence Interval: 0.37 days
Each bar represents 4 days



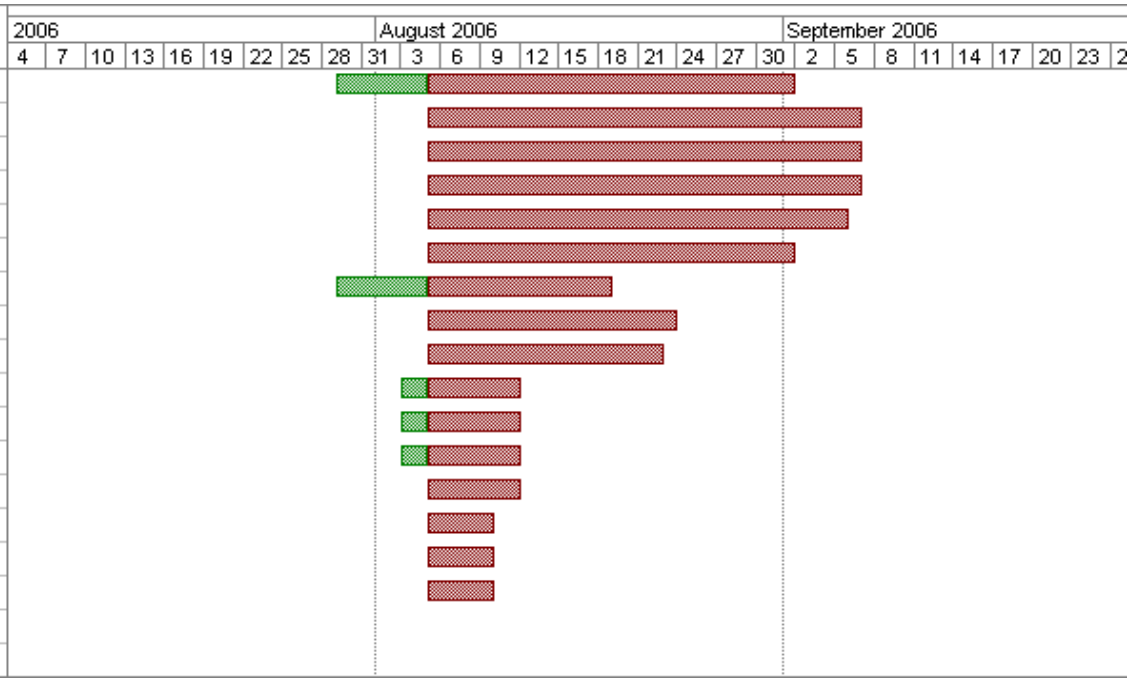
Completion Probability Table

Prob	Date	Prob	Date
0.05	Wed 8/16/06	0.55	Wed 9/6/06
0.10	Mon 8/21/06	0.60	Thu 9/7/06
0.15	Wed 8/23/06	0.65	Fri 9/8/06
0.20	Thu 8/24/06	0.70	Mon 9/11/06
0.25	Mon 8/28/06	0.75	Wed 9/13/06
0.30	Tue 8/29/06	0.80	Thu 9/14/06
0.35	Wed 8/30/06	0.85	Tue 9/19/06
0.40	Thu 8/31/06	0.90	Fri 9/22/06
0.45	Fri 9/1/06	0.95	Thu 9/28/06
0.50	Mon 9/4/06	1.00	Fri 10/27/06

Schedule data is 7/18/06 – no chance to make?
Lags added two months (July 6 to Sept 13) at 75%

Sensitivity Analysis

ID	Task Name	Early Finish	Late Finish	Range
24	Integrate System	Fri 7/28/06	Fri 9/1/06	25 days
4	Design Unit A	Fri 8/4/06	Wed 9/6/06	23 days
5	Builid Unit A	Fri 8/4/06	Wed 9/6/06	23 days
6	Test Unit A	Fri 8/4/06	Wed 9/6/06	23 days
14	Test Unit C	Fri 8/4/06	Tue 9/5/06	22 days
23	Integrate Units B anc	Fri 8/4/06	Fri 9/1/06	20 days
25	Test System	Fri 7/28/06	Fri 8/18/06	15 days
12	Design Unit C	Fri 8/4/06	Wed 8/23/06	13 days
13	Builid Unit C	Fri 8/4/06	Tue 8/22/06	12 days
16	Design Unit D	Wed 8/2/06	Fri 8/11/06	7 days
17	Builid Unit D	Wed 8/2/06	Fri 8/11/06	7 days
18	Test Unit D	Wed 8/2/06	Fri 8/11/06	7 days
22	Integrate Units A anc	Fri 8/4/06	Fri 8/11/06	5 days
8	Design Unit B	Fri 8/4/06	Wed 8/9/06	3 days
9	Builid Unit B	Fri 8/4/06	Wed 8/9/06	3 days
10	Test Unit B	Fri 8/4/06	Wed 8/9/06	3 days
2	Release Work Order	Fri 8/4/06	Fri 8/4/06	0 days
20	Customer Review before	Fri 8/4/06	Fri 8/4/06	0 days



- Loose view of “opportunities” due to impeding lags

Agenda

- 9:00 – 9:15 Introductions & Overview - Lehman
- 9:15 – 10:15 Intro to EVM/Evolving Policy – Driessnack
- 10:15 – 10:45 Break
- 10:45 – 11:15 EVM/Policy continued - Driessnack
- 11:15 – 12:00 1st Soupçon of Statistics – Dr Hulkower
- 12:00 – 1:15 Lunch (On Your Own)
- 1:15 – 2:00 Scheduling and Risk Analysis - Driessnack
- 2:00 – 2:30 2nd Soupçon of Statistics – Dr Hulkower
- 2:30 – 3:00 Break
- 3:00 – 3:30 Estimates part 1 - Driessnack
- 3:30 - 4:00 Estimates part 2 - Dr Hulkower

"Creating Customer-Focused Success"

A Second Soupçon of Statistics for Cost Analysts

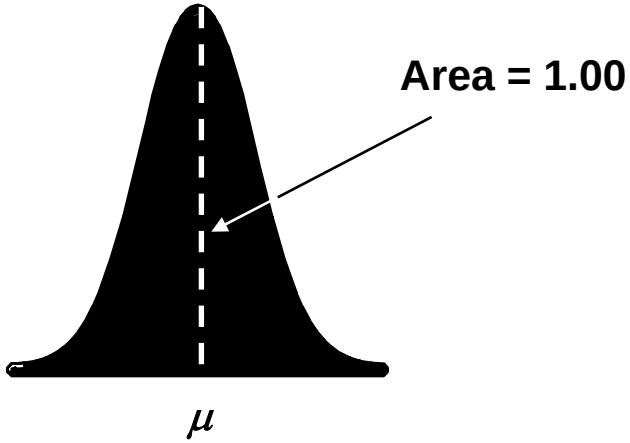
Charts by Stephen A. Book, Ph.D. and Raymond P. Covert

Outline

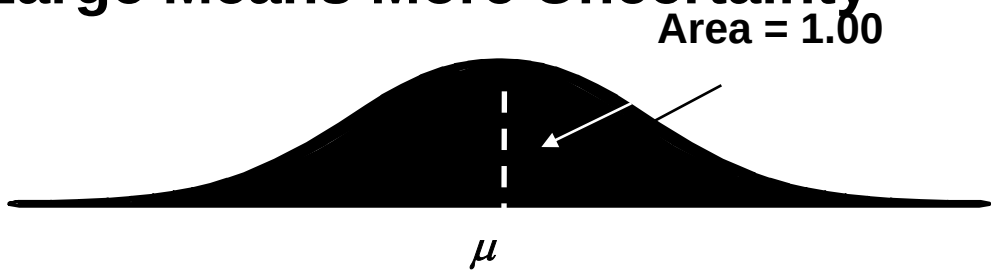
- Introduction
- Product Moment and Rank Correlation
- The Different Types of Correlation
- Impact of Correlation on Total Cost Distribution
- Summary

Variance (σ^2) Measures Uncertainty

- σ^2 Small Means Less Uncertainty



- σ^2 Large Means More Uncertainty



What is Correlation?

- **Correlation is:**
  - **A statistical measure of association between two variables**
  - **A measurement of how strongly variables are related, or change, with each other.**
    - **If two variables tend to move up or down together, they are said to be positively correlated. If they tend to move in opposite directions, they are said to be negatively correlated.**
- **The most common statistic for measuring association is the Pearson (linear) correlation coefficient, ρ**
  - **Another is the Spearman (rank) correlation coefficient, ρ_S, which is used in Crystal Ball and @Risk**

Source: www.statlets.com/usermanual/glossary.htm

Pearson "Product-Moment" Correlation

- **Suppose *X* and *Y* are two random variables**
  - $\mu_X = E(X), \ \mu_Y = E(Y)$ **are their Expected Values ("Means")**
  - **True Theorem:** $E(X+Y) = E(X) + E(Y) = \mu_X + \mu_Y$
  - **False Theorem:** $E(XY) = E(X)E(Y)$
  - $Cov(X,Y) = E(XY) - E(X)E(Y) =$ **"Covariance" of *X* and *Y***

- $Var(X) = Cov(X,X) = E(X^2) - [E(X)]^2 =$ **"Variance" of *X***

  $Var(Y) = Cov(Y,Y) = E(Y^2) - [E(Y)]^2 =$ **"Variance" of *Y***

- $Corr(X,Y) = \dfrac{Cov(X,Y)}{\sqrt{Var(X)Var(Y)}} =$ **"Correlation" of *X* and *Y* =** ρ_{XY}

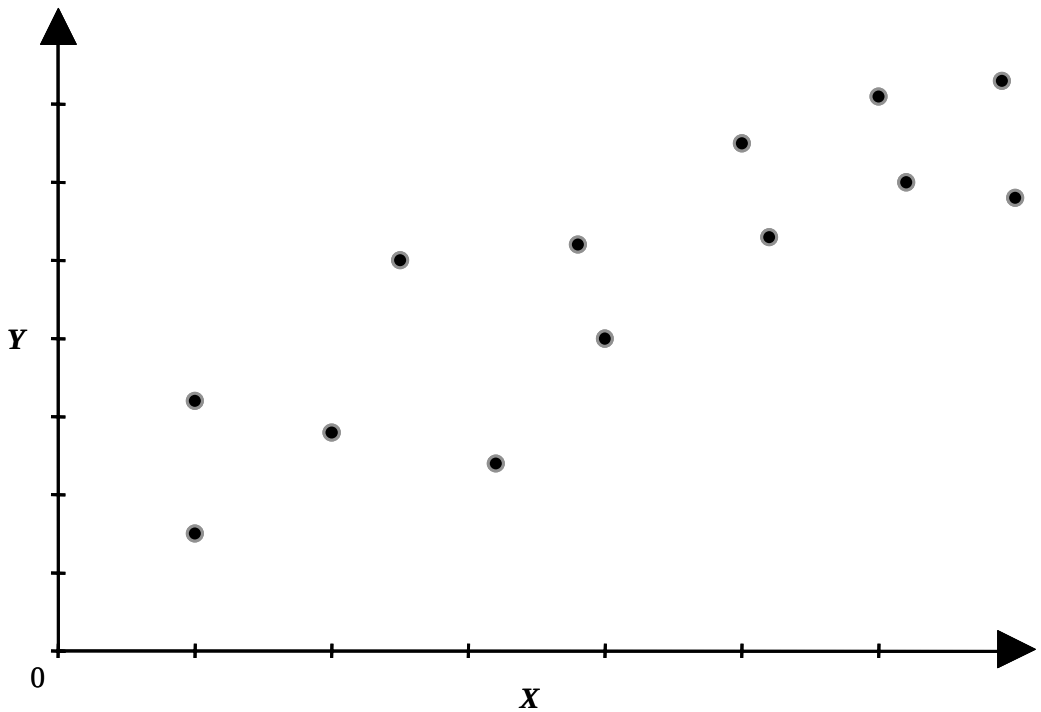
  $Var(X) = \sigma_X^2, \ Var(Y) = \sigma_Y^2,$

  $Cov(X,Y) = \rho_{XY}\sigma_X\sigma_Y$

Pearson Correlation Measures Linearity

- **A statistical relationship between two random variables *X* and *Y***

- **Realizations of *Y*, given actual values of *X*:**



Spearman Rank Correlation Coefficient

- **Data Structure**

CASE	RANK OF X_i VALUE	RANK OF X_j VALUE	DIFFERENCE	SQUARED DIFFERENCE
#1	r_1	c_1	$d_1 = c_1 - r_1$	d_1^2
#2	r_2	c_2	$d_2 = c_2 - r_2$	d_2^2
#3	r_3	c_3	$d_3 = c_3 - r_3$	d_3^2
⋮	⋮	⋮	⋮	⋮
#n	r_n	c_n	$d_n = c_n - r_n$	d_n^2
SUMS	$\frac{n(n+1)}{2}$	$\frac{n(n+1)}{2}$	$\sum d = \sum c - \sum r = 0$	$\sum d^2$

$$\rho\left(X_i, X_j\right) = 1 - \frac{6\sum d^2}{n\left(n^2 - 1\right)} = \rho_s$$

- **Statistics Theorem: Spearman Rank Correlation Coefficient equals Pearson (Linear) Correlation Coefficient calculated between the two sets of ranks**

Product Moment vs. Rank Correlation

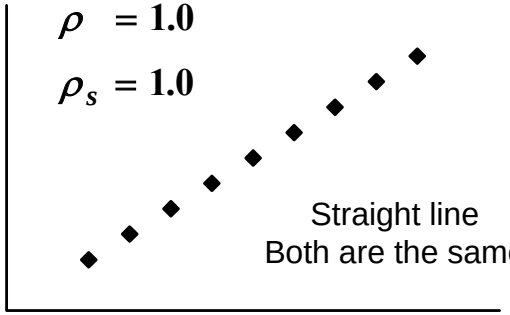
- **Pearson Product-Moment Linear Correlation** $\rho(X,Y)$
  - $\rho(X,Y)=\pm 1$ **if and only if *X* and *Y* are linearly related, i.e., the least-squares linear relationship between *X* and *Y* allows us to predict *Y* precisely, given *X***
  - $\rho^2(X,Y)$ **= proportion of variation in *Y* that can be explained on the basis of a least-squares linear relationship between *X* and *Y***
  - $\rho(X,Y)=0$ **if and only if the least-squares linear relationship between *X* and *Y* provides no ability to predict *Y*, given *X***
- **Spearman Rank Correlation** $\rho_s(X,Y)$
  - $\rho_s(X,Y)=1$ **if and only if the largest value of *X* corresponds to the largest value of *Y* , the second largest, ... , etc.**
  - $\rho_s(X,Y)=-1$ **if and only if the largest value of *X* corresponds to the smallest value of *Y*, etc.**
  - $\rho_s(X,Y)=0$ **if and only if the rank of a particular *X* among all *X* values provides no ability to predict the rank of the corresponding *Y* among all *Y* values**

Product Moment vs. Rank Correlation (Cont'd)

LINEAR

$\rho = 1.0$

$\rho_s = 1.0$

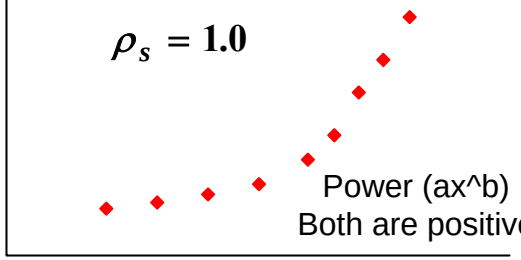


Straight line
Both are the same

POWER

$\rho = 0.8$

$\rho_s = 1.0$

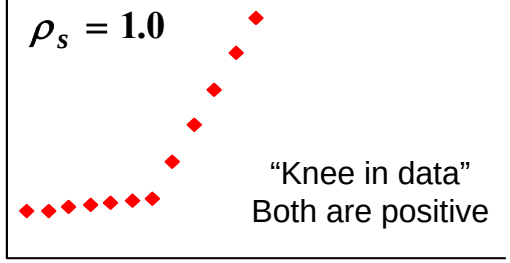


Power (ax^b)
Both are positive

"KNEE"

$\rho = 0.6$

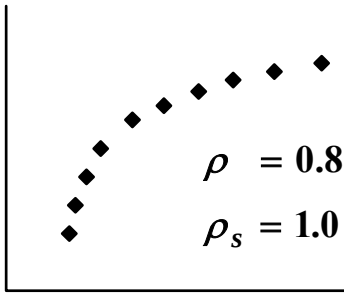
$\rho_s = 1.0$



"Knee in data"
Both are positive

More Nonlinear

ROOT

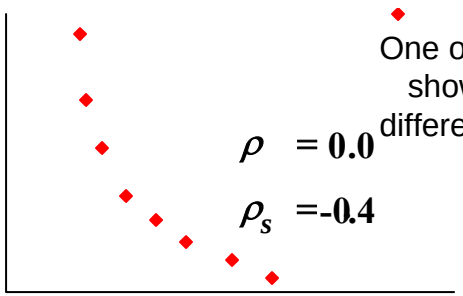


Root
Both are positive

$\rho = 0.8$

$\rho_s = 1.0$

DECAY w/ OUTLIER



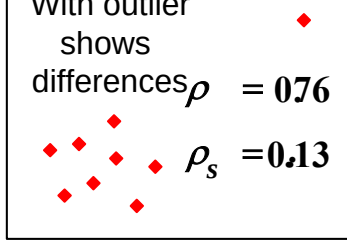
One outlier shows differences

$\rho = 0.0$

$\rho_s = -0.4$

RANDOM w/ OUTLIER

Random
With outlier shows differences



$\rho = 076$

$\rho_s = 0.13$

Linear Data gives similar ρ and ρ_s

What Does Correlation Measure?

- **PEARSON Correlation** measures extent of **LINEARITY** of a relationship between two random variables
- **SPEARMAN Correlation** measures extent of **MONOTONICITY** of a relationship between two random variables

A way to remember:

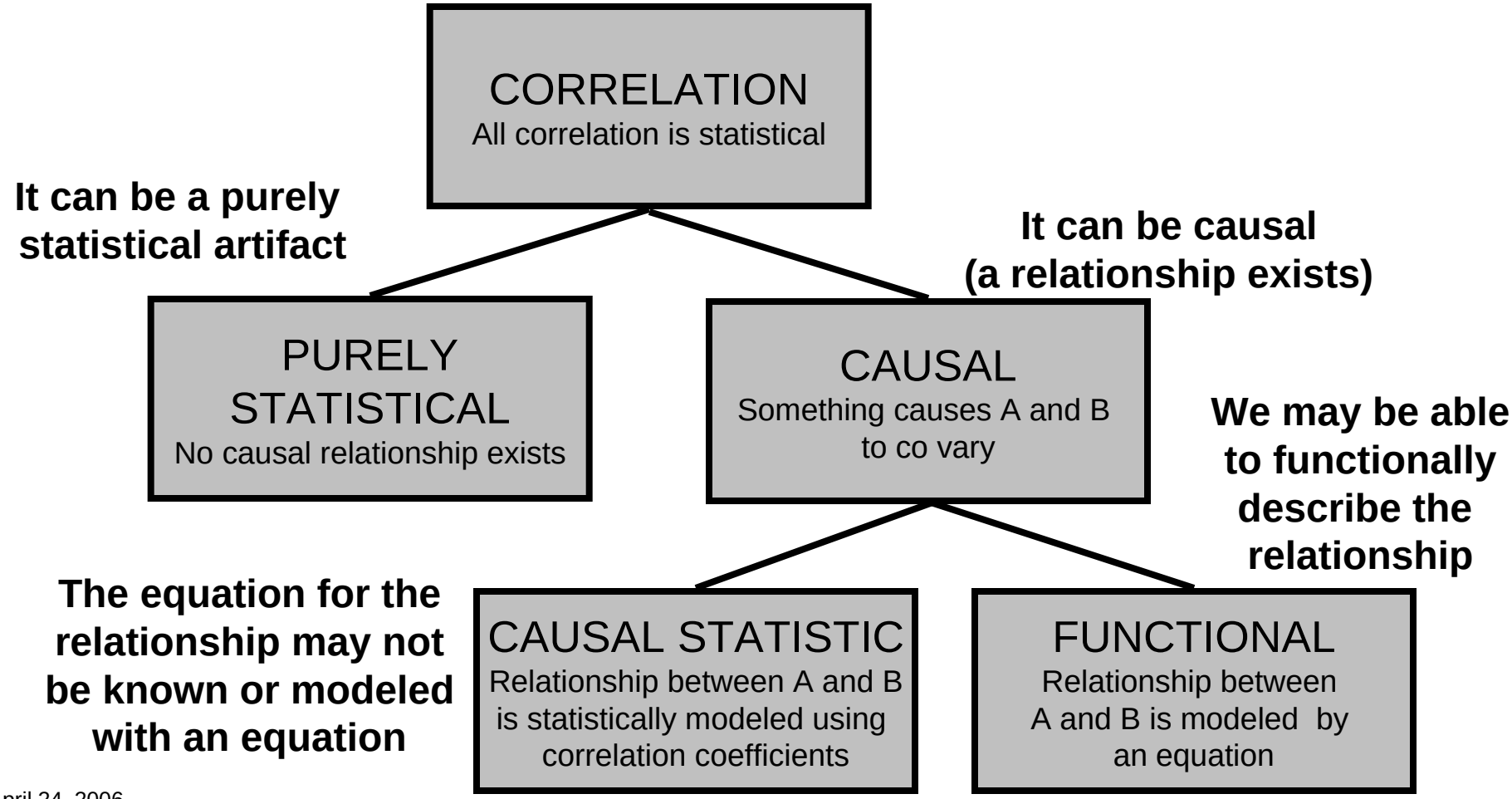
…L M N O P Q R S…

Linear is Pearson

Rank is Spearman

The Different Types of Correlation

- **Correlation is a statistic – so all correlation is statistical**



Correlation Example

- **Consider this statement based on some statistical data:**
  - **"Shark attacks are correlated to ice cream sales".**
- **This <u>DOES NOT</u> mean that ice cream sales increase because of shark attacks (or vice versa).**
- **More shark attacks happen in warm weather, and more ice cream is consumed in warm weather, therefore ice cream sales and shark attacks are positively correlated.**
  - **So as temperatures increase, more people swim in the ocean and more people eat ice cream.**
  - **Something (the temperature) causes A (shark attacks) and B (ice cream sales) to covary, but we do not know the exact equation.**

Correlation tells us the degree to which two variables covary, not why

Purely Statistical Correlation

- **Purely statistical correlation exists in all of our cost estimates and models**
- **The effects may not be apparent**
- **Book pointed out that correlation is important when statistically summing WBS element costs**
  - **The impact of even small amounts of correlation become large as the number of WBS elements increases**
  - **Even with perfect inputs (exact values for cost drivers), CERs have errors and the sum of the variances does not account for the total model variance**

Total Cost Variance

- **Remember, the total cost variance, σ^2**
- $$\sigma_{Total}^2 = \sum_{k=1}^{n} \sigma_k^2 \boxed{+ 2\sum_{k=2}^{n} \sum_{j=1}^{k-1} \rho_{jk} \sigma_j \sigma_k}$$
- $\sigma^2 = \sigma^T [\rho] \sigma$
  - $[\rho]$ = **Correlation matrix (full matrix)**
  - σ = **Vector of standard deviations (cost space)**
  - **Excel commands**
    - SIGMA_TOT=SQRT(MMULT(MMULT(TRANSPOSE(SIGMA),RHO),SIGMA))

Correlation is essential in calculating variance!

Representing Correlation Matrices

- **Full Matrix (Have to use this when you use analytic function: $\sigma^2=\sigma^T[\rho]\sigma$)**

1	0.2	0.14	0.37	0.2
0.2	1	0.06	0.15	0.12
0.14	0.06	1	-0.2	0.06
0.37	0.15	-0.2	1	0.15
0.2	0.12	0.06	0.15	1

- **Upper Triangular:**

1	0.2	0.14	0.37	0.2
	1	0.06	0.15	0.12
		1	-0.2	0.06
			1	0.15
				1

- **Lower Triangular:**

1				
0.2	1			
0.14	0.06	1		
0.37	0.15	-0.2	1	
0.2	0.12	0.06	0.15	1

All 3 representations mean the same thing

Representing Correlation Matrices

- **Single value shorthand:** $\begin{bmatrix} 1 & \rho & \rho & \rho & \rho \\ \rho & 1 & \rho & \rho & \rho \\ \rho & \rho & 1 & \rho & \rho \\ \rho & \rho & \rho & 1 & \rho \\ \rho & \rho & \rho & \rho & 1 \end{bmatrix} = \rho$
  - **This means all of the off diagonal terms are the same value**
- **The Rules:**
  - **Always positive semi-definite**
  - **Diagonal terms always 1.0**
  - **Off diagonal terms are correlation values**
  - **Columns and rows are transposed,** $\rho_{j,k} = \rho_{k,j}$

Risks are Correlated

- **Resolving one WBS element's risk issues by spending more money on them often induces cost increases in several other elements as well**
  - **For example, technical risks in radar subsystem can cause growth in power, platform, software, and other subsystems**
  - **Schedule slippage due to problems in one WBS element lead to cost growth in other elements ("Standing Army Effect")**
  - **Hardware risks that remain unresolved late in program often have to be circumvented by making expensive last-minute fixes to the software (which then show up as software cost overruns)**
- **As we will soon see, inter-element correlation tends to increase the variance (i.e., spread) of the total-cost probability distribution**
- **Numerical values of inter-WBS-element correlations are difficult to estimate, but that's another story**

Correlation Affects the Variance

- $X_1,\ X_2,\ \ldots,\ X_n$ are Costs of WBS Elements (Random Variables)
- Total Cost = $\sum_{k=1}^{n} X_k = X_1 + X_2 + \ldots + X_n$
- Mean of Total Cost = $E\left(\sum_{k=1}^{n} X_k\right) = \sum_{k=1}^{n} E(X_k) = \sum_{k=1}^{n} \mu_k$
- Variance of Total Cost = $Var\left(\sum_{k=1}^{n} X_k\right)$

$$= \sum_{k=1}^{n} Var(X_k) + 2\sum_{j=2}^{n}\sum_{i=1}^{j-1} Cov(X_i, X_j)$$

$$= \sum_{k=1}^{n} \sigma_k^2 + 2\sum_{j=2}^{n}\sum_{i=1}^{j-1} \rho_{ij}\sigma_i\sigma_j$$

Important Distinction

- **PEARSON Correlation plays an explicit, well-defined role in establishing the sigma value (as well as the range) of the Total-Cost Distribution**
- **SPEARMAN Correlation does not appear explicitly in the formula for the Total-Cost sigma (Its impact on sigma is not known)**

Does Correlation Matter?

- If WBS-Element costs are uncorrelated (all $\rho_{ij} = 0$), then Variance of Total Cost = $\sum_{k=1}^{n} \sigma_k^2$
- If WBS-Element Costs are correlated, then Variance of Total Cost = $\sum_{k=1}^{n} \sigma_k^2 + 2\sum_{j=2}^{n} \sum_{i=1}^{j-1} \rho_{ij}\sigma_i\sigma_j$
  - Positive correlations increase dispersion
  - Negative correlations reduce dispersion
- If ("Worst" Case) all correlations $\rho_{ij} = 1$, then Variance of Total Cost = $\left(\sum_{k=1}^{n} \sigma_k\right)^2 >> \sum_{k=1}^{n} \sigma_k^2$
- "Ignoring" correlation Issue is tantamount to setting all

$$\rho_{ij} = 0$$

Yes, Correlation Matters

- **Suppose for simplicity**
  - **There are *n* Cost Elements** $C_1,\ C_2,\ \ldots,\ C_n$
  - **Each** $Var(C_i) = \sigma^2$
  - **Each** $Corr(C_i, C_j) = \rho \le 1$
- **Total Cost** $C = \sum_{k=1}^{n} C_i$
  - $$Var(C) = \sum_{k=1}^{n} Var(C_i) + 2\rho \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \sqrt{Var(C_i)\, Var(C_j)}$$

$$= n\sigma^2 + n(n-1)\rho\sigma^2$$

$$= n\sigma^2\left(1 + (n-1)\rho\right)$$

Correlation	0	ρ	1
$Var(C)$	$n\sigma^2$	$n\sigma^2\left(1 + (n-1)\rho\right)$	$n^2\sigma^2$

Magnitude of Correlation Impact

- **Percent underestimation of Total-Cost Sigma $\left(=\sqrt{Var(C)}\right)$ when correlation is assumed to be 0 instead of ρ is 100% times ...**

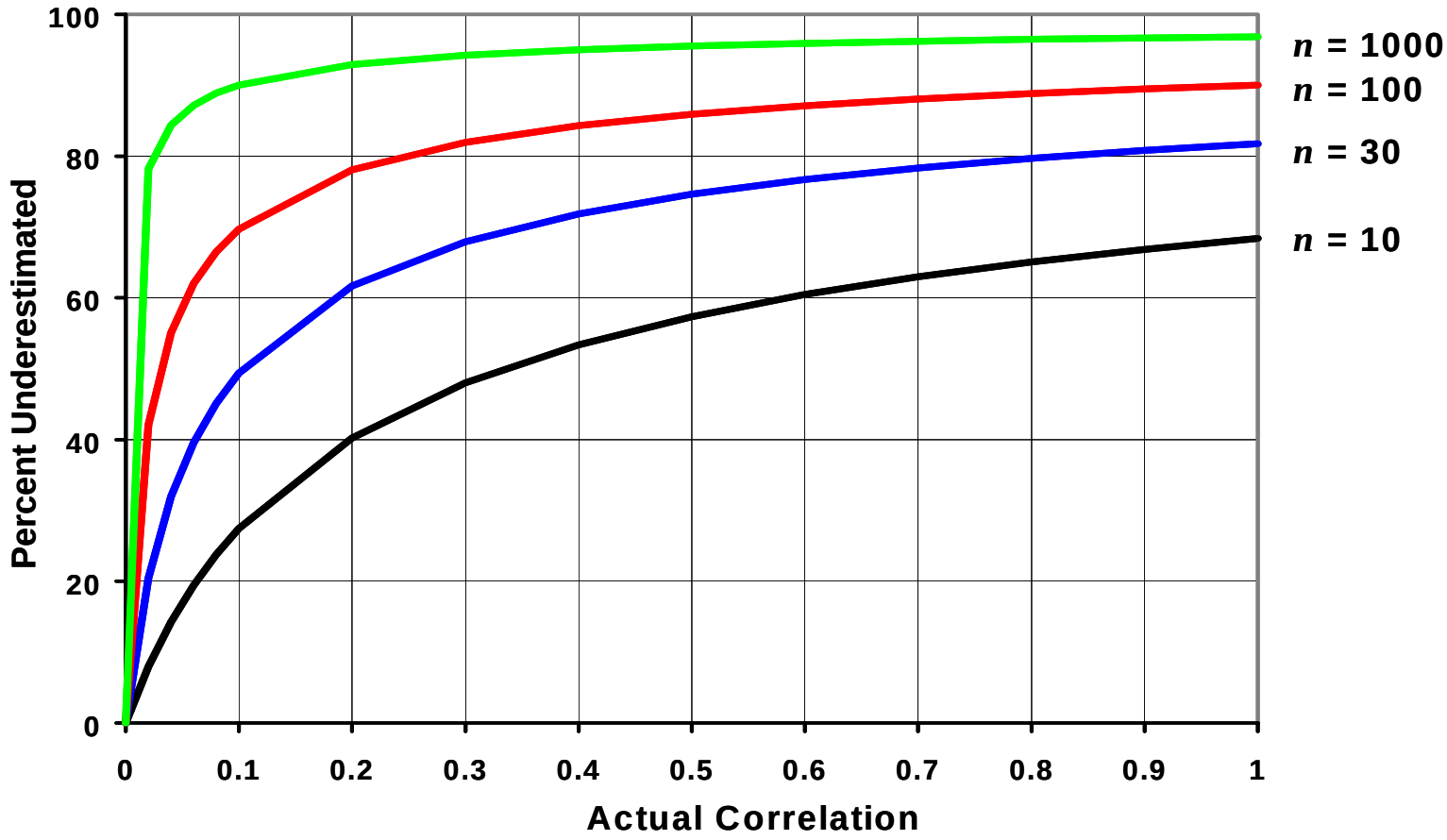
$$\frac{\sqrt{n}\sigma\sqrt{1+(n-1)\rho}-\sqrt{n}\sigma}{\sqrt{n}\sigma\sqrt{1+(n-1)\rho}}=1-\sqrt{\frac{1}{1+(n-1)\rho}}$$

- **Percent overestimation of Total-Cost Sigma $\left(=\sqrt{Var(C)}\right)$ when correlation is assumed to be 1 instead of ρ is 100% times ...**

$$\frac{n\sigma-\sqrt{n}\sigma\sqrt{1+(n-1)\rho}}{\sqrt{n}\sigma\sqrt{1+(n-1)\rho}}=\sqrt{\frac{n}{1+(n-1)\rho}}-1$$

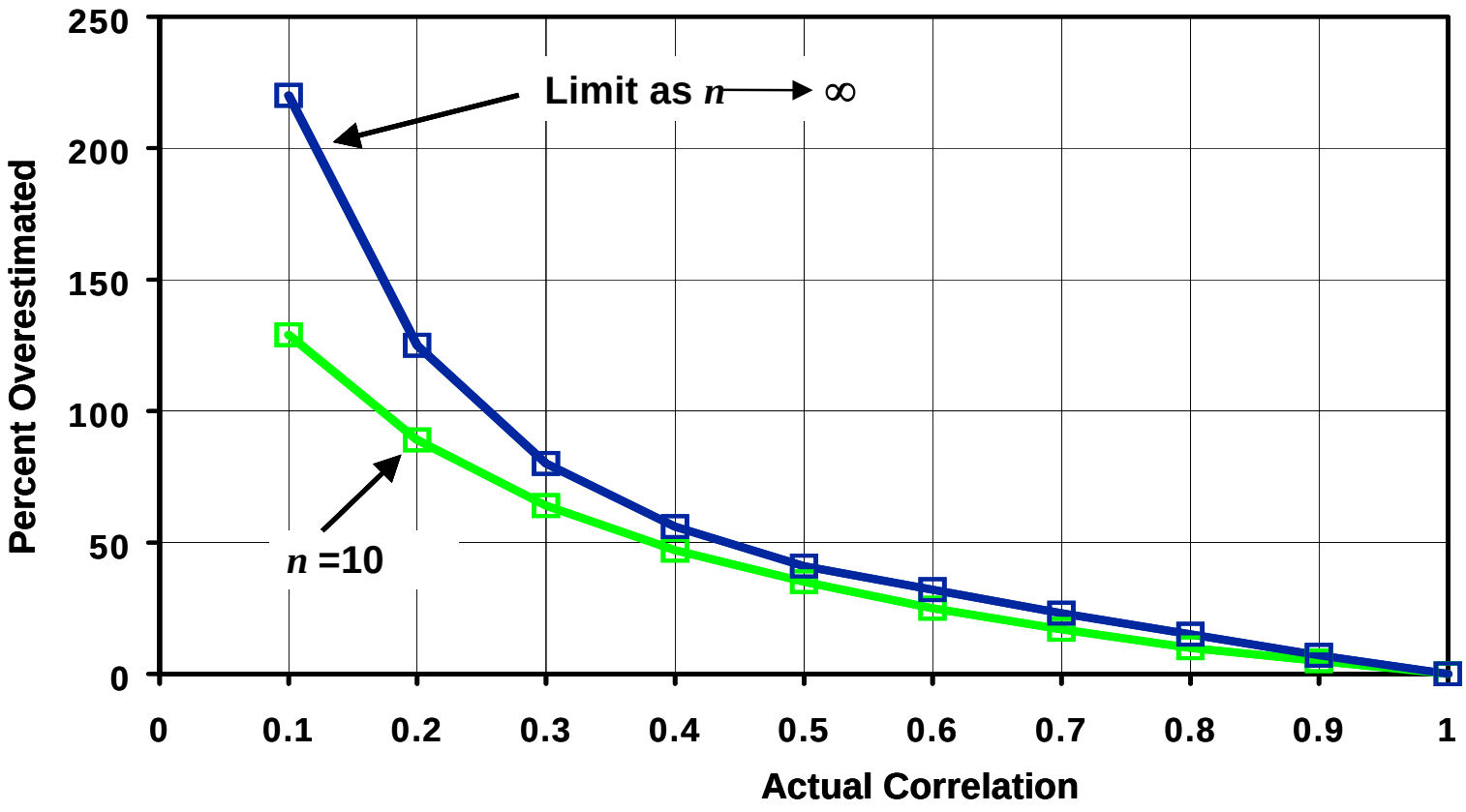
Maximum Possible Underestimation of Total-Cost Sigma

Percent Underestimated When Correlation Assumed to be 0 Instead of ρ



Maximum Possible Overestimation of Total-Cost Sigma

Percent Overestimated When Correlation Assumed to be 1 Instead of ρ



Impact of Nonzero Correlation Value

- **Percent underestimation of Total-Cost Sigma $\left(=\sqrt{Var(C)}\right)$ when correlation is assumed to be ρ_1 instead of $\rho_2 > \rho_1$ is 100% times ...**

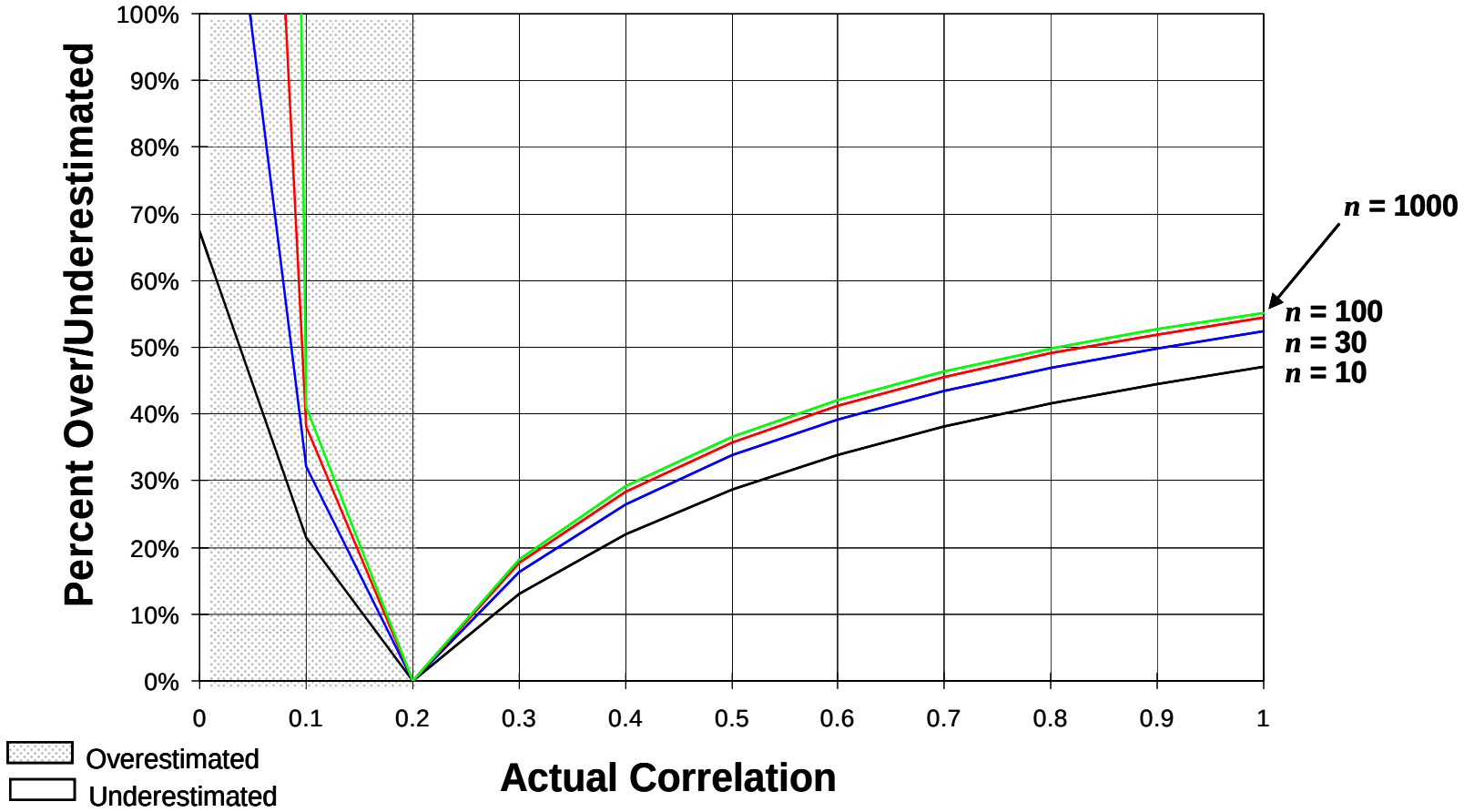
$$1-\sqrt{\frac{1+(n-1)\rho_1}{1+(n-1)\rho_2}}$$

- **Percent overestimation of Total-Cost Sigma $\left(=\sqrt{Var(C)}\right)$ when correlation is assumed to be ρ_2 instead of $\rho_1 < \rho_2$ is 100% times ...**

$$\sqrt{\frac{1+(n-1)\rho_2}{1+(n-1)\rho_1}}-1$$

Maximum Possible Over- and Under-Estimation of Total-Cost Sigma

Percent Over/Underestimated When Correlation Assumed to be 0.2 Instead of ρ



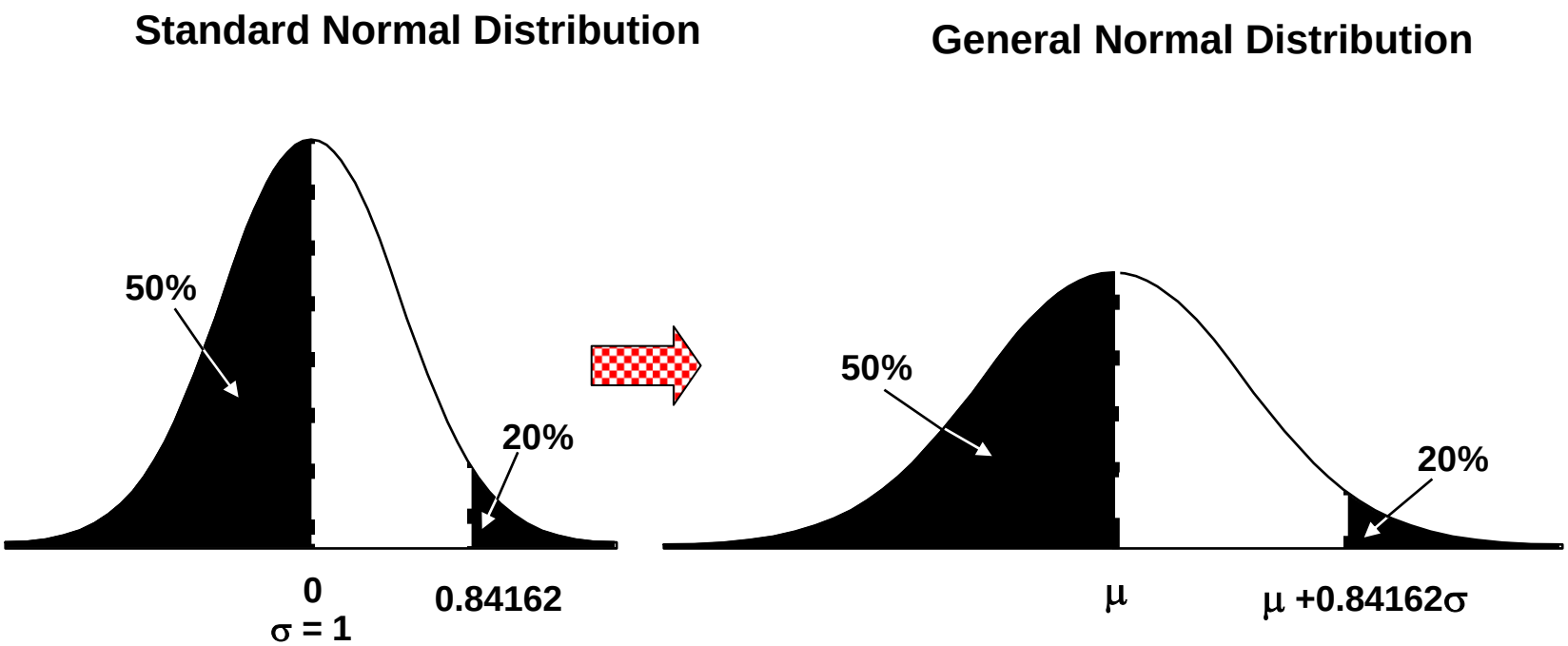
Selection of Correlation Values

- **"Ignoring" correlation issue is equivalent to assuming that risks are uncorrelated, i.e., that all correlations are zero**
- **Square of correlation (namely, R^2) represents percentage of variation in one WBS element's cost that is attributable to influence of another's**
- **Reasonable choice of nonzero values brings you closer to truth**
  - **Most elements are, in fact, pairwise correlated**
  - **0.2 is at "knee" of curve for small number (10) of WBS elements, thereby providing most of the benefits at least commitment. The knee of the curve changes with increasing number of WBS elements**

By How Much Does Correlation Affect an Estimate?

- **Statistical context for discussing this question**
  - **Assume that Central Limit Theorem applies, so that Total-Cost Distribution is normal (Gaussian)**
  - **If all pairwise correlations are assumed to be zero, then Total-Cost Sigma Value =** $\sigma_T = \sqrt{\sum_{k=1}^{n} \sigma_k^2}$
  - **If pairwise correlations are assumed to be ρ_{ij}, then Total-Cost Sigma Value =** $\sigma_T = \sqrt{\sum_{k=1}^{n} \sigma_k^2 + 2\sum_{j=2}^{n} \sum_{i=1}^{j-1} \rho_{ij}\sigma_i\sigma_j}$
- **80th Percentile of the Cost Distribution**
  - **80th-Percentile of "Standard Normal" Distribution is 0.84162**
  - **80th-Percentile of General Normal Distribution is μ+0.84162σ**
  - **Numerical value of σ depends on pairwise correlations**

Graphs of Standard, General Normal Distributions with 80th Percentile Points



Note: Graphs not drawn to scale.

Percentage Increase in 80th Percentile Estimates due to Effects of Correlation

Coefficient of Variation = σ/μ = 0.4

- **Statistical Context for this table: Central Limit Theorem applies, so that Total-Cost Distribution is Normal (Gaussian)**
- **This table applies to all Normal (Gaussian) distributions whose numerical value of σ is 40% of its numerical value of μ**

Number of WBS Elements	Increase in 80th-Percentile Estimate for Correlation ρ over Estimate for Zero Correlation for ρ =										
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
10	0.00%	3.64%	6.48%	8.89%	11.01%	12.94%	14.72%	16.37%	17.93%	19.40%	20.80%
20	0.00%	4.92%	8.34%	11.12%	13.53%	15.68%	17.65%	19.47%	21.18%	22.78%	24.31%
30	0.00%	5.64%	9.31%	12.24%	14.76%	17.01%	19.05%	20.93%	22.69%	24.35%	25.93%
40	0.00%	6.13%	9.94%	12.96%	15.54%	17.83%	19.91%	21.83%	23.62%	25.31%	26.91%
50	0.00%	6.49%	10.39%	13.46%	16.08%	18.40%	20.51%	22.46%	24.27%	25.98%	27.59%
60	0.00%	6.78%	10.74%	13.85%	16.49%	18.84%	20.96%	22.92%	24.75%	26.47%	28.10%
70	0.00%	7.00%	11.01%	14.15%	16.82%	19.18%	21.32%	23.29%	25.13%	26.86%	28.49%
80	0.00%	7.19%	11.24%	14.40%	17.08%	19.46%	21.61%	23.59%	25.44%	27.17%	28.82%
90	0.00%	7.36%	11.43%	14.61%	17.31%	19.69%	21.85%	23.84%	25.69%	27.43%	29.08%
100	0.00%	7.50%	11.60%	14.79%	17.50%	19.89%	22.05%	24.05%	25.91%	27.66%	29.31%

Summary

- **WBS-Element risks (and therefore costs) are typically correlated**
  - **Correlations cannot be applied if estimate is developed in a non-statistical context**
  - **Therefore the typical "point" estimate does not account for correlations between WBS elements**
  - **This is one more reason that every cost-analysis job (of which earned value analysis is an important special case) requires a risk analysis**
- **Correlations impact probable cost range**
- **Correlations also impact cost estimates, namely mode, median, (but not the mean) other percentiles of the cost probability distribution**
- **Your estimate and range will be closer to reality if you use reasonable nonzero correlations rather than zeroes**

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- 9:00 – 9:15 Introductions & Overview - Lehman
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- 3:30 - 4:00 Estimates part 2 - Dr Hulkower

Estimating the Cost of a Defense Contract with Performance Indices
Do the Old Methods Still Work?

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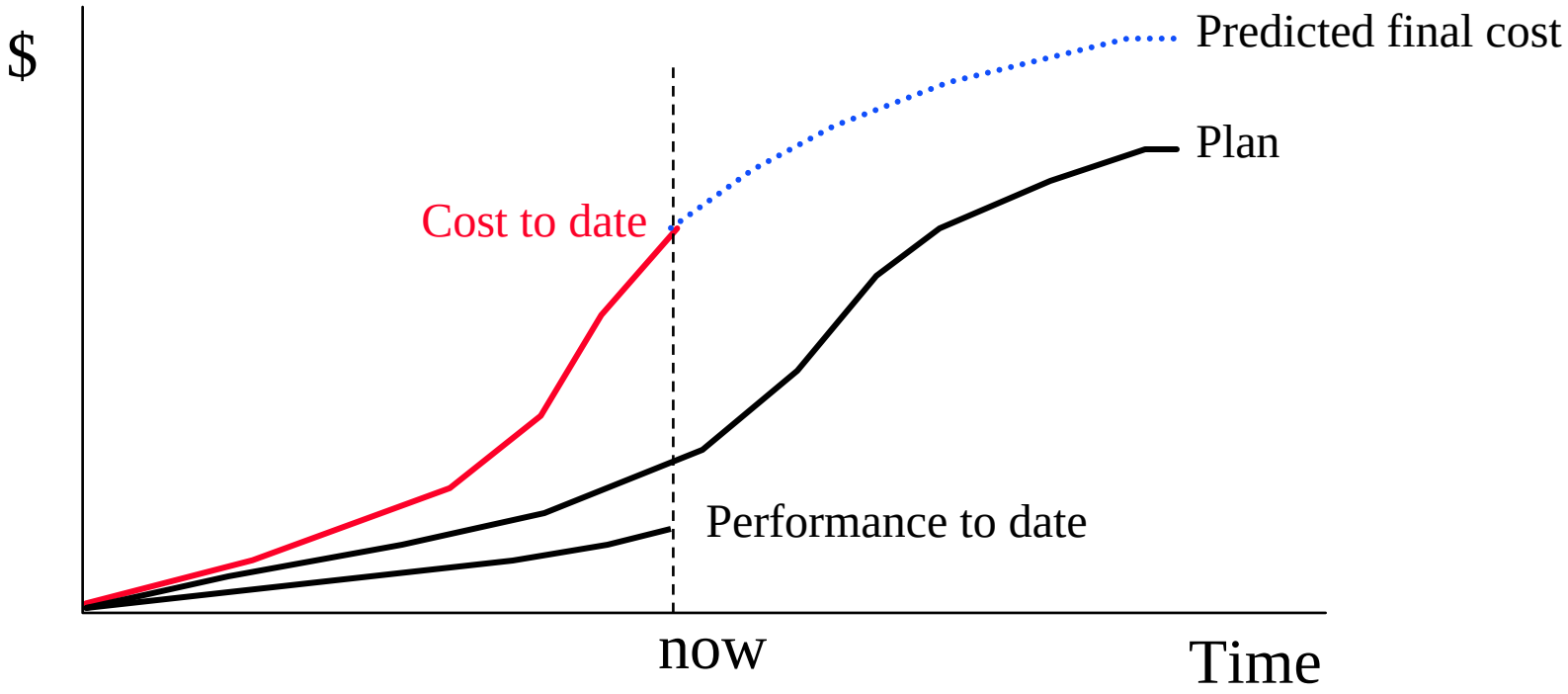
20 May 2002

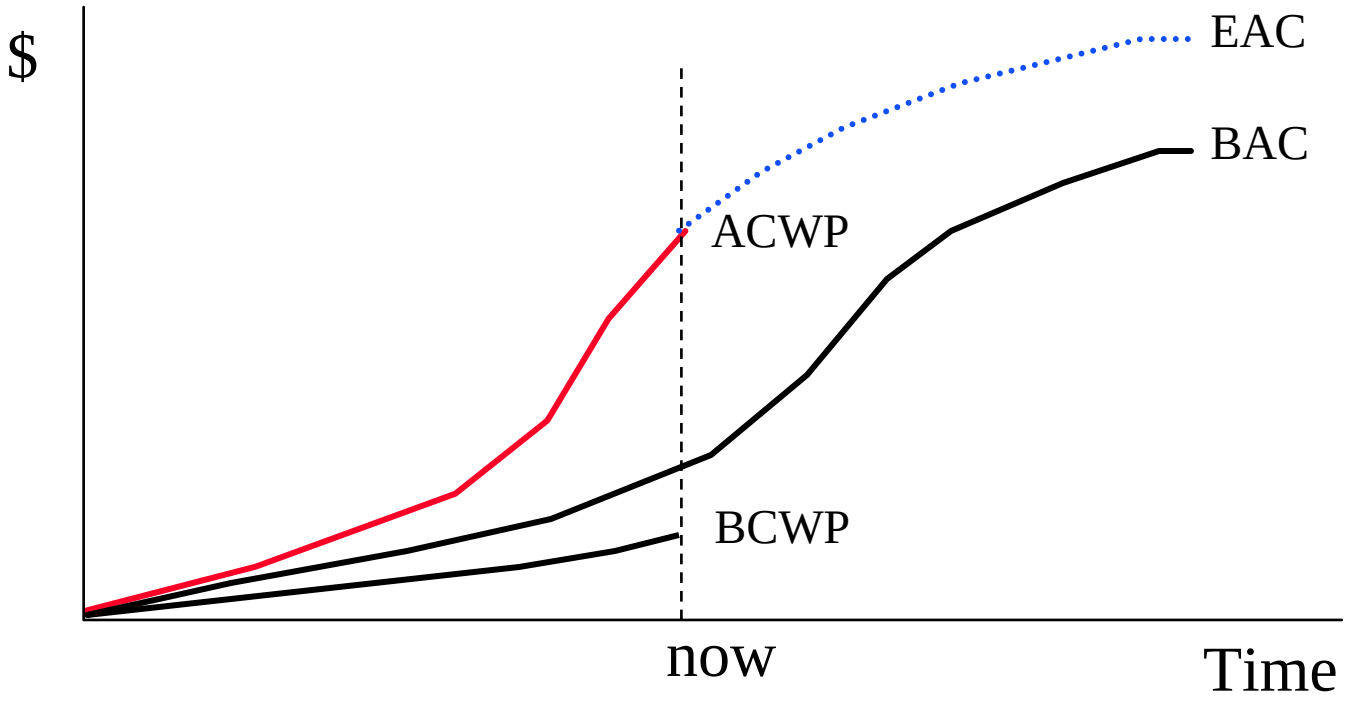
EAC Formula

EAC = Costs to date + Estimated Cost of Remaining Work



EAC Formula

EAC = ACWPcum + [(BAC - BCWPcum)/Performance Factor]



Twelve index-based EAC formulas

Index	*Monthly*	*Cumulative*	*Average*
CPI	x	x	x
SPI	x	x	x
w1(CPI) + w2(SPI)	x	x	x
CPI x SPI	x	x	x

Which one is best?

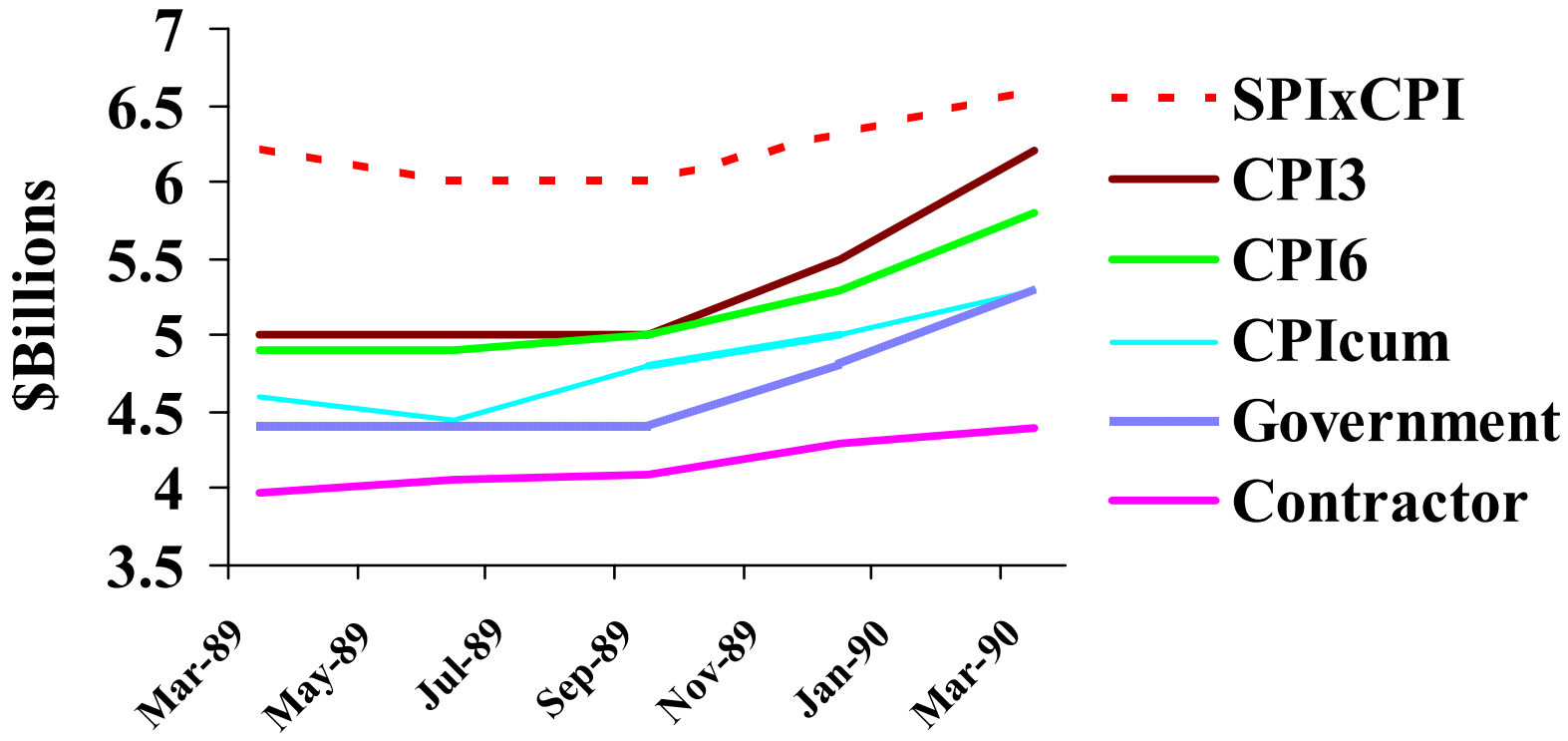
A-12 CPR Data (April 1990, $MIL)

BCWS	BCWP	ACWP	SV	CV	BAC	LRE	VAC
2080	1491	1950	-589	-459	4046	4400	-354

Index	*Value*	*EAC*
CPI x SPI	0.5481	6,612
SPI	0.7168	5,514
.8CPI + .2SPI	0.7551	5,334
CPI	0.7646	5,292

Which EAC is best?

Estimates at Completion
A-12 Program



Evaluating the EAC

DOD Experience: No single EAC formula is always best.

(Christensen, Antolini, McKinney 1992)

Navy (Covach, et al., 1981 14 Development, 13 Production)	
State of completion	**Best index-based formula**
Early (0-40%)	CPI3, CPI6, SCIc
Middle (20-80%)	CPI3, CPI6, CPIc, SCI
Late (60-100%)	CPI3, CPI6, CPI12

Army (Howard and Bright, 1981, 11 Develoment)	
State of completion	**Best index-based formula**
Early (0-40%)	Regression, Composite, SPIc, SCI
Middle (31-80%)	CPI3, CPI6, CPI12, SCI
Late (81-100%)	CPIc, SCI

Evaluating the EAC

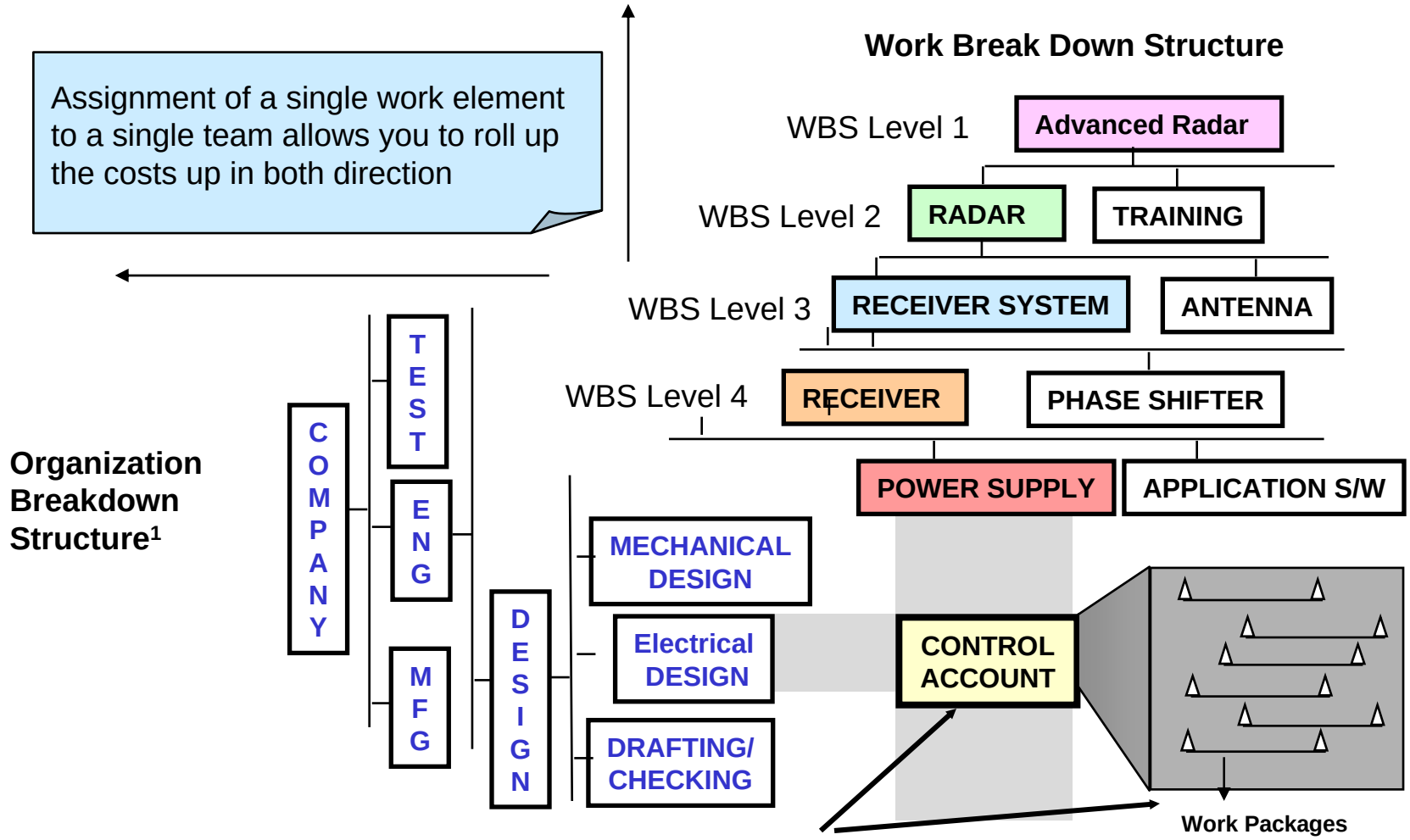
DOD Experience: No single EAC formula is always best.

(Christensen, Antolini, McKinney 1992)

Air Force (Riedel and Chance, 1989 16 Development 40 Production)						
Phase	**System**	**25%**	**50%**	**75%**	**100%**	**Overall**
Devel	Aircraft	SCIc	CPI3	CPI3	20/80	SCIc
Prod	Aircraft	SCIc	CPI3	SCIc	CPIc	SCIc
Devel	Avionics	SCIc	CPI3	SCIc	CPIc	CPI3
Prod	Avionics	20/80	SCIc	20/80	SCIc	20/80
Devel	Engine	CPImon	SCIc	CPI3	CPI3	CPI3
Prod	Engine	PC	CPIc	SCIc	PC	CPIc

Control Account OBS and WBS

Assignment of a single work element to a single team allows you to roll up the costs up in both direction



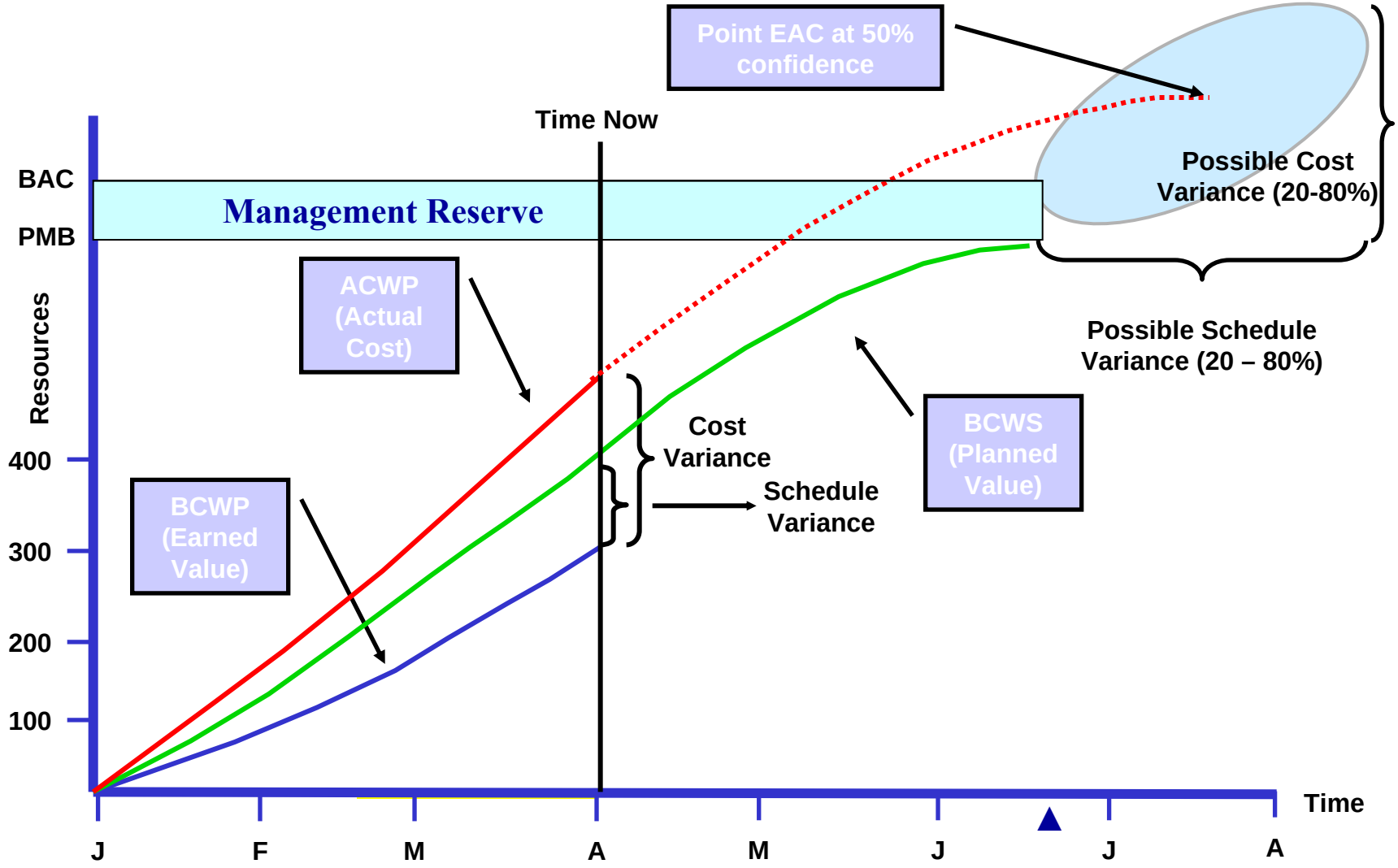
[1]Organization performing the work

This is the level for analysis … cost, schedule, risk

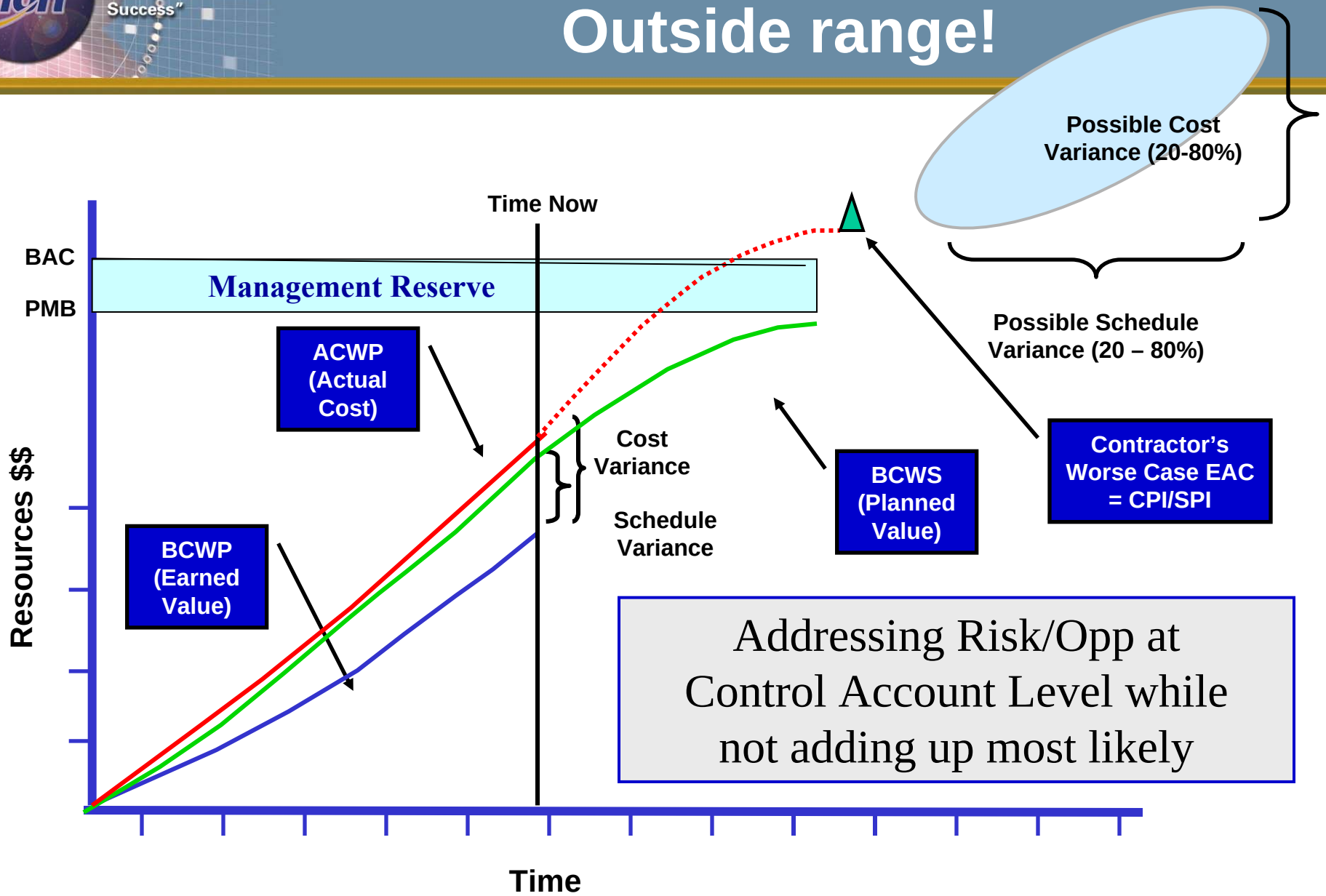
Cost/Schedule Analysis should include Risk Analysis

- **WBS-Element are Uncertain in Dollars/Time**
- **Baseline should consider the effects of uncertainty**
  - **Not a risk or opportunity till baseline is set**
  - **Should model WBS-Element as Random Variables with a Distribution of values**
  - **Combine Element Distributions to Generate Cumulative Distribution of Total System …in time and dollars**
  - **Determine confidence from Cumulative Distribution to establish baseline needed to cover Risk at an Acceptable Level**

How an Estimate at Complete Should be Characterized



Analysis shows Unrealistic Outside range!



Addressing Risk/Opp at Control Account Level while not adding up most likely

Repeatable Analysis
Utilize EAC/ETC formulas

- **Use EAC formulas at lower level to set ranges**
  - **Moving 3 and 6 month average, Cur and/or Cum**
  - **CPI and SPI as stand-alone or combination**
  - **Also uses CAMs Latest Revised Estimate as "most likely" This enables capture of ongoing technical assessment**
- **Use correlation … establish at IBR and control**
  - **Capture integration effects and structural effects**
  - **Never assume no correlation, when in doubt, use 0.2**
  - **Deriving correlations from WBS, OBS and IMS structures. These represent the relationships in PM plan**
- **Use simulation/analytic method to get the cumulative probability distribution for the EAC**

Avoid adding "most likely" with WBS Level 1 data

MCR Approach

How is this all done?

- **Detailed analysis includes IMS/WBS/OBS structure**
  - **Build a correlation structure upfront … senior analyst**
  - **Figure outputs …usually Level 2 WBS or OBS (IPT)**
- **Build view in wInsight …various EAC figures**
  - **Data cut/pasted from wInsight to Excel**
- **Analysis ... various inputs**
  - **If/then statements highlight "issues" to address**
    - **Select best, LRE, worse estimate from EAC formulas**
    - **Assess triangles….like anything over 200% of LRE?**
    - **Open/Completed CA … update correlations levels**
  - **Bring in Risks/Opp by WBS/OBS/IMS … how addressed?**
    - **… general discussion with CAM/Cost/Schedule/Risk team**
  - **Use statistical methods to build CPD curves**
    - **Compare to other methods….cost tools**

EV Data (wInsight Report)

WBS	BCWS	BCWP	ACWP	SV	CV	BAC	LRE	CPI	SPI
1.3.1.1	266.7	266.7	1,170.10	0	-903.4	266.7	1,176.20	0.228	1
1.3.1.2	100.9	100.9	73.6	0	27.3	100.9	73.6	1.371	1
1.3.1.3	36.1	36.1	54.8	0	-18.7	36.1	54.8	0.659	1
1.3.1.4	34.2	34.2	59.5	0	-25.3	34.2	59.6	0.575	1
1.3.1.5	43.5	43.5	95.7	0	-52.2	43.5	95.7	0.455	1
1.3.1.6	37.4	37.4	145.1	0	-107.7	37.4	145.1	0.258	1
1.3.1.7	34.9	34.9	121.1	0	-86.2	34.9	121.2	0.288	1
1.3.1.9	119.7	119.7	202.3	0	-82.6	119.7	202.3	0.592	1
1.3.10.1	663.6	520.7	654	-142.9	-133.3	10,340.40	10,197.90	0.796	0.785
1.3.11.1	2,127.30	2,125.10	2,919.10	-2.2	-794	4,755.60	5,172.90	0.728	0.999
1.3.12.1	452.5	217.7	76.4	-234.8	141.3	649	634.8	2.849	0.481
1.3.12.2	136.9	133.7	83.2	-3.2	50.5	173.2	164.3	1.607	0.977
1.3.13.1	419.8	419.8	162.4	0	257.4	559.3	450.3	2.585	1
1.3.13.2	744.4	540.7	411.6	-203.7	129.1	5,872.30	5,857.90	1.314	0.726
1.3.13.3	134	116.4	102	-17.6	14.4	453.7	439.6	1.141	0.869
1.3.13.7	1.5	1.5	0	0	1.5	252	254.1	0	1
1.3.15.1	73.8	73.8	92.3	0	-18.5	1,067.10	1,003.20	0.8	1
1.3.16.1	73.7	73.7	82.9	0	-9.2	73.7	83	0.889	1
1.3.17.1	977.8	977.8	1,292.10	0	-314.3	2,387.30	2,589.40	0.757	1
1.3.17.2	71.7	71.6	87.1	-0.1	-15.5	184.3	209.5	0.822	0.999
1.3.17.3	1,585.80	1,572.60	1,456.10	-13.2	116.5	3,383.60	3,270.30	1.08	0.992
1.3.17.4	0	0	0	0	0	4,664.50	4,395.70	0	0
1.3.17.5	12.6	0	1.9	-12.6	-1.9	218.5	45	0	0
1.3.2.1	403.3	403.3	829	0	-425.7	403.3	829.2	0.486	1
1.3.2.2	4,512.30	4,727.80	3,465.40	215.5	1,262.40	7,305.70	5,593.50	1.364	1.048
1.3.2.3	0	212	201.2	212	10.8	1,701.60	1,095.80	1.054	0
1.3.2.4	0	0	0	0	0	1,004.60	638.5	0	0

EV Data (wInsight Report)

WBS	MovAvg3	MovAvg6	CpiSpi	CumCpiFc	CumSpiFc				L	M	H
1.3.1.1	1,170.10	1,170.10	1,170.10	1,170.10	266.70	1170.1	1170.1	1181.801	**1922.2**	**1922.2**	**1941.422**
1.3.1.2	73.6	73.6	73.6	73.6	100.9	73.6	73.6	74.336			
1.3.1.3	54.8	54.8	54.8	54.8	36.1	54.8	54.8	55.348			
1.3.1.4	59.6	59.5	59.5	59.5	34.2	59.5	59.5	60.095			
1.3.1.5	95.7	95.7	95.7	95.7	43.5	95.7	95.7	96.657			
1.3.1.6	145.1	145.1	145.1	145.1	37.4	145.1	145.1	146.551			
1.3.1.7	121.2	121.1	121.1	121.1	34.9	121.1	121.1	122.311			
1.3.1.9	202.3	202.3	202.3	202.3	119.7	202.3	202.3	204.323			
1.3.10.1	15,053.80	15,638.10	16,372.40	12,987.60	13,172.48	12987.6	15053.8	16372.4			
1.3.11.1	8,344.40	7,819.40	6,536.20	6,532.40	4,760.36	4760.36	6536.2	8344.4			
1.3.12.1	167.1	116.9	391	227.8	1349.272349	116.9	227.8	1349.272	**223.9**	**335.6**	**1526.55**
1.3.12.2	107.5	107	108.4	107.8	177.2773797	107	107.8	177.2774			
1.3.13.1	242.8	255.6	216.4	216.4	559.3	216.4	242.8	559.3	**5084.2**	**5967.3**	**9421.962**
1.3.13.2	5,188.90	5,270.80	5,999.20	4,470.20	8,088.57	4470.2	5270.8	8088.567			
1.3.13.3	453.7	453.7	442.3	397.6	522.0943613	397.6	453.7	522.0944			
1.3.13.7	0	0	0	0	252	0	0	252			
1.3.15.1	2,390.40	1,976.10	1,334.60	1,334.60	1,067.10	1067.1	1334.6	2390.4			
1.3.16.1	82.9	82.9	82.9	82.9	73.7	82.9	82.9	83.729			
1.3.17.1	2,436.70	2,802.10	3,154.70	3,154.70	2,387.30	2387.3	2802.1	3154.7	**5676.5**	**11002.48**	**11675.17**
1.3.17.2	87.1	86.4	224.4	224.2	184.4844845	86.4	184.4845	224.4			
1.3.17.3	3,093.60	2,984.30	3,147.00	3,132.90	3,410.89	2984.3	3132.9	3410.887			
1.3.17.4	4,664.50	4,664.50	4,664.50	4,664.50	#DIV/0!	0	4664.5	4664.5			
1.3.17.5	218.5	218.5	218.5	218.5	#DIV/0!	218.5	218.5	220.685			
1.3.2.1	829	829	829	829	403.3	829	829	837.29	**5585**	**8660.6**	**10427.88**
1.3.2.2	4,554.80	5,085.20	5,268.80	5,355.00	6,971.09	4554.8	5268.8	6971.088			
1.3.2.3	1,501.50	1,614.90	201.2	1,614.90	#DIV/0!	201.2	1558.2	1614.9			
1.3.2.4	1,004.60	1,004.60	1,004.60	1,004.60	#DIV/0!	0	1004.6	1004.6			

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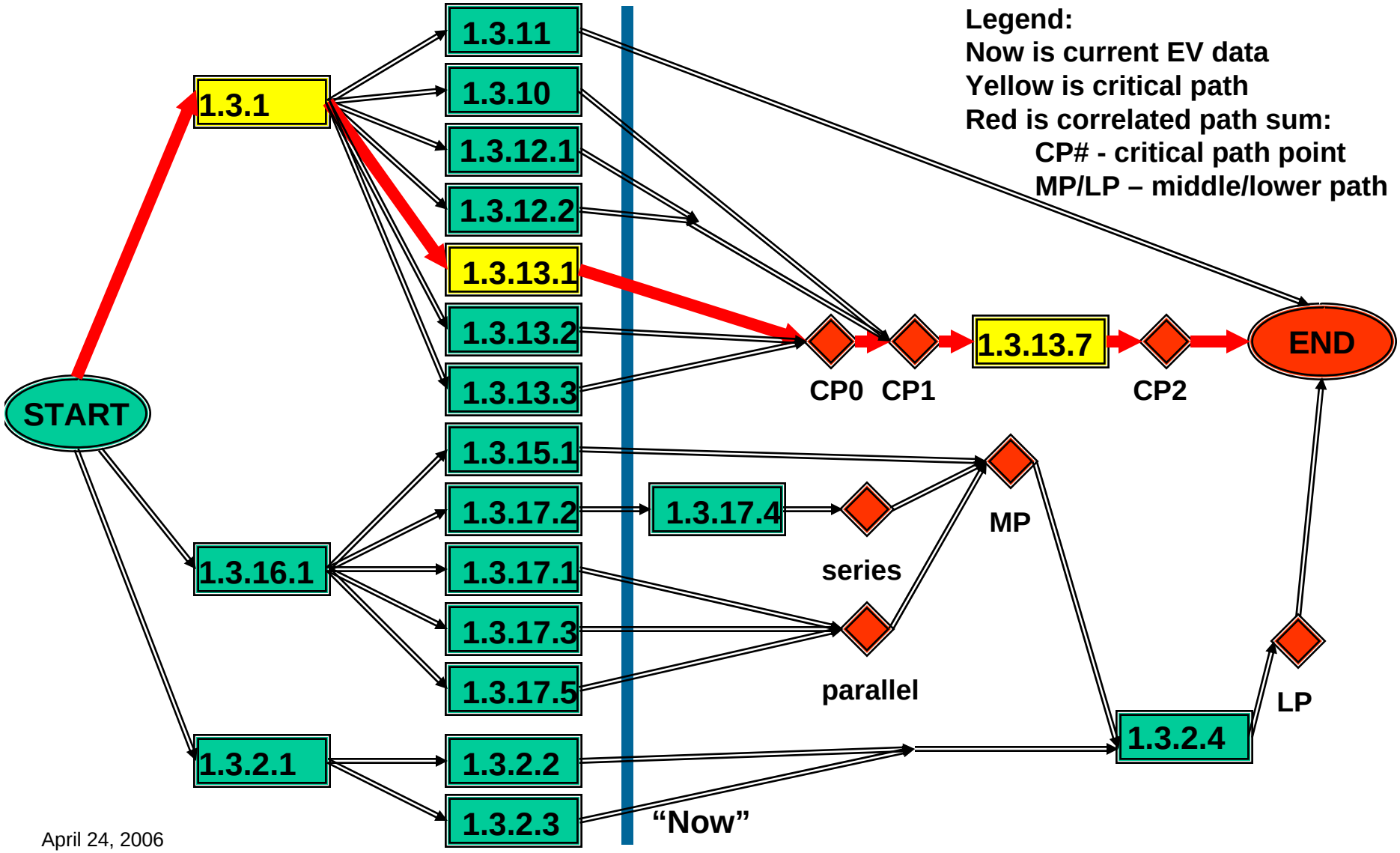
Correlated Schedule Path Sum Methods

- Path integral methods and Bayesian methods are used in economics to handle strong correlations and fat-tailed distributions
- Fat-tailed distributions incorporate the risks of failure and realizations of opportunity that are unusual. Nevertheless economies and projects can boom or bust. This is not captured with thin tailed distributions which implicitly assume equilibrium.
- The correlated schedule path sum method we describe below can be regarded as a linearized approximation to path integral and Bayesian methods which can handle the possibility of non equilibrium boom or bust behavior.

Correlated Schedule Path Sum Methods (Cont'd)

1. Decompose project schedule down to desired level
2. For each critical path and branching probability separately: Assign 1.0 correlation coefficients to paths that join at integration points (events that integrate schedule network flow). Assign 1.0 correlation coefficients to WBS elements that succeed each other on the critical path.
3. Without paths joining at integration points assign 0.2 among items that are related technically.
4. Otherwise leave uncorrelated.
5. Isolate the lowest level paths that have integration points and 1.0 correlations and sum them separately along with related WBS elements that are isolated (and 0.2 correlated).
6. Do the FRISK correlated sum.
7. For each higher level repeat steps 2-4.
8. Do FRISK correlated sum at that level and continue until you get the sum at the highest level.
9. Combine the highest level sums for each critical path as a strict branching probability sum (no FRISK).

Example Schedule



Critical Path Integration Points – CP0

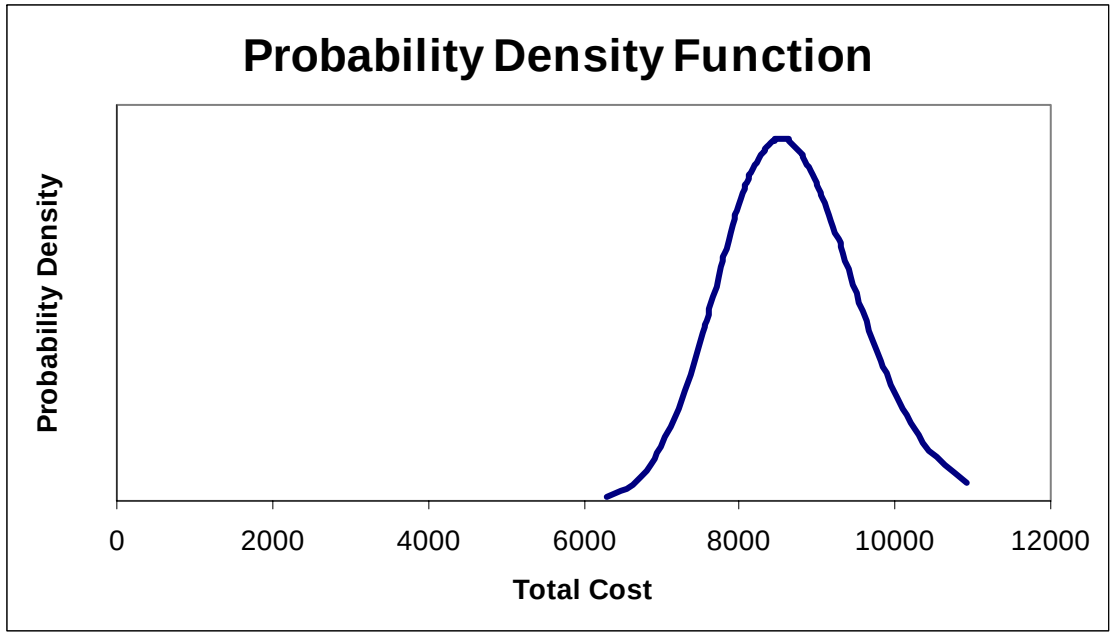
Correlation Matrix: Edit Lower-Traingular Portion

NAME	L	ML	H	WBS 1	WBS 2	WBS 3	WBS 4
1.3.1	1922.2	1922.2	1941.42	1			
1.3.13.1	216.4	242.8	559.3	1	1		
1.3.13.2	4470.2	5270.8	8088.57	1	1	1	
1.3.13.3	397.6	453.7	522.094	1	1	1	1

$	8,669	Mean (Expected Cost)
$	8,624	Median (50th percentile)
$	8,536	Mode (Most Likely)
$	884	Std. Deviation

Confidence Percentiles

$	7,296	5%
$	7,571	10%
$	7,762	15%
$	7,917	20%
$	8,053	25%
$	8,177	30%
$	8,293	35%
$	8,405	40%
$	8,515	45%
$	8,624	50%
$	8,735	55%
$	8,849	60%
$	8,969	65%
$	9,097	70%
$	9,237	75%
$	9,395	80%
$	9,583	85%
$	9,825	90%
$	10,195	95%



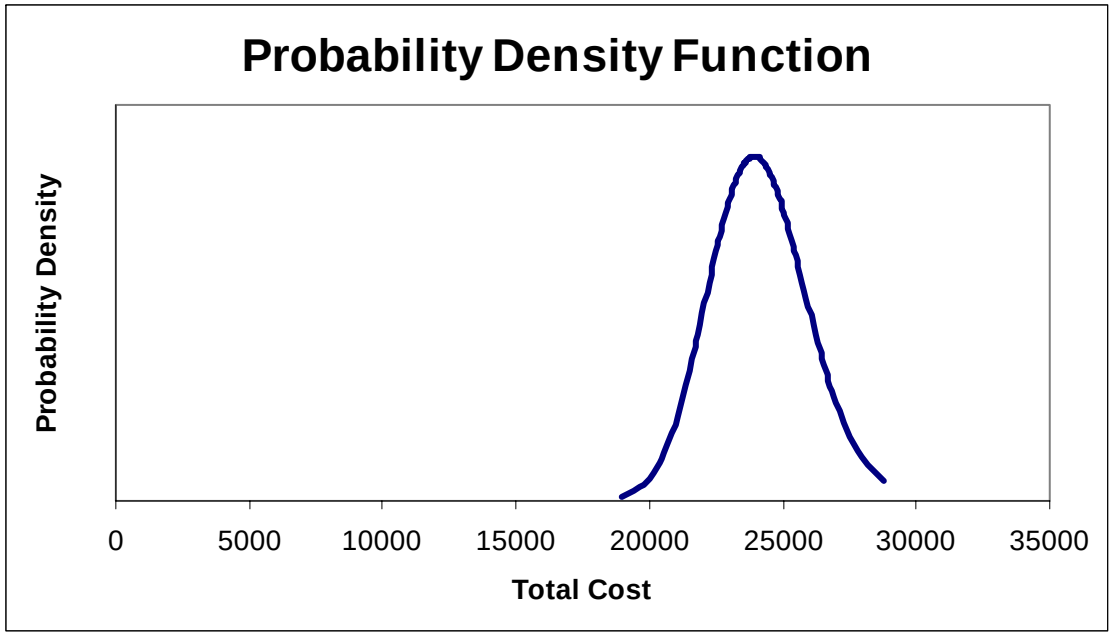
Critical Path Integration Points – CP1

NAME	L	ML	H	Correlation Matrix: Edit Lower-Traingular Portion WBS 1	WBS 2	WBS 3	WBS 4
Critical Path 0	6299	8668	10926	1			
1.3.12.1	116.9	227.8	1349.27	1	1		
1.3.12.2	107	107.8	177.277	1	1	1	
1.3.10	12987.6	15053.8	16372.4	1	0.2	0.2	1

$ 24,131	Mean (Expected Cost)
$ 24,060	Median (50th percentile)
$ 23,920	Mode (Most Likely)
$ 1,849	Std. Deviation

Confidence Percentiles

$ 21,215	5%
$ 21,813	10%
$ 22,226	15%
$ 22,560	20%
$ 22,850	25%
$ 23,114	30%
$ 23,361	35%
$ 23,598	40%
$ 23,830	45%
$ 24,060	50%
$ 24,293	55%
$ 24,531	60%
$ 24,780	65%
$ 25,045	70%
$ 25,335	75%
$ 25,661	80%
$ 26,046	85%
$ 26,539	90%
$ 27,287	95%



Critical Path Integration Points – CP2

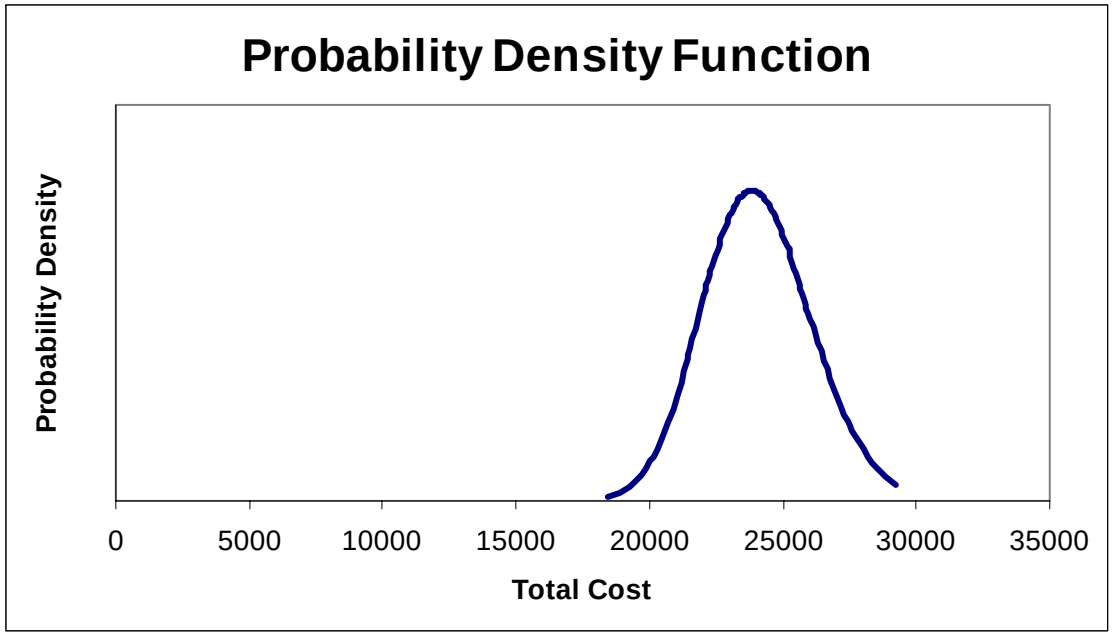
Correlation Matrix: Edit Lower-Traingular Portion

NAME	L	ML	H	WBS 1	WBS 2
Critical Path 1	18994	24293	28748	1	
1.3.13.7	0	0	252	1	1

$ 24,096 Mean (Expected Cost)
$ 24,009 Median (50th percentile)
$ 23,836 Mode (Most Likely)
$ 2,053 Std. Deviation

Confidence Percentiles

$ 20,875	5%
$ 21,530	10%
$ 21,983	15%
$ 22,350	20%
$ 22,670	25%
$ 22,961	30%
$ 23,235	35%
$ 23,497	40%
$ 23,753	45%
$ 24,009	50%
$ 24,267	55%
$ 24,532	60%
$ 24,808	65%
$ 25,104	70%
$ 25,426	75%
$ 25,790	80%
$ 26,221	85%
$ 26,773	90%
$ 27,613	95%



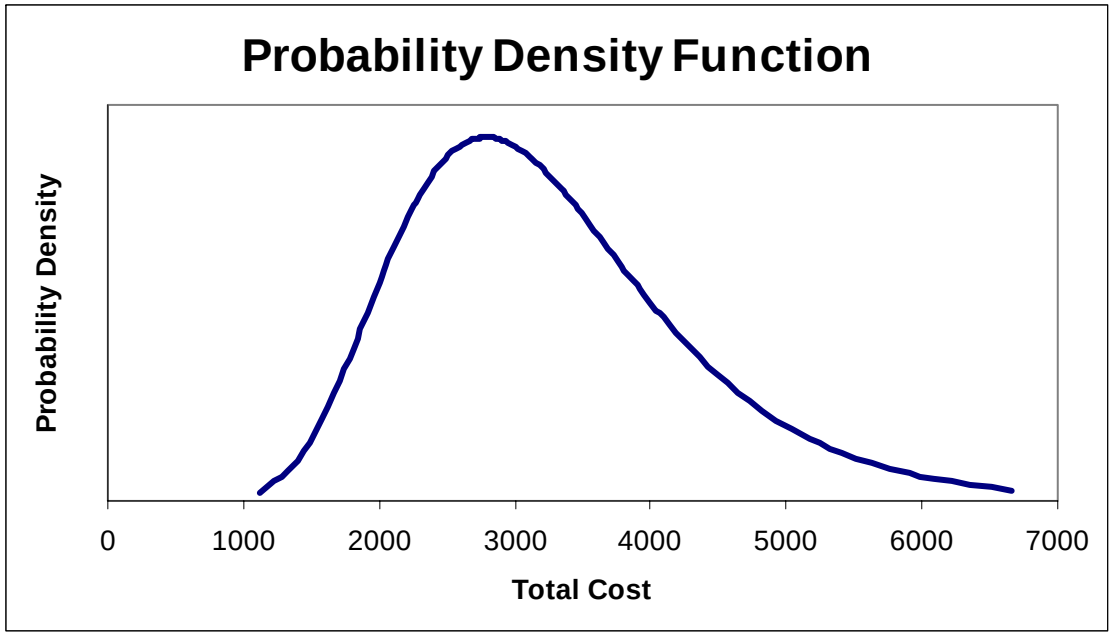
Non Critical Path Integration Points – series

NAME	L	ML	H	Correlation Matrix: Edit Lower-Traingular Portion WBS 1	WBS 2
1.3.17.2	86.4	184.484	224.4	1	
1.3.17.4	0	4664.5	4664.5	0.2	1

$	3,275	Mean (Expected Cost)
$	3,103	Median (50th percentile)
$	2,785	Mode (Most Likely)
$	1,106	Std. Deviation

Confidence Percentiles

$	1,807	5%
$	2,036	10%
$	2,207	15%
$	2,353	20%
$	2,486	25%
$	2,612	30%
$	2,734	35%
$	2,855	40%
$	2,977	45%
$	3,103	50%
$	3,233	55%
$	3,372	60%
$	3,521	65%
$	3,686	70%
$	3,872	75%
$	4,091	80%
$	4,361	85%
$	4,727	90%
$	5,326	95%



Non Critical Path Integration Points – parallel

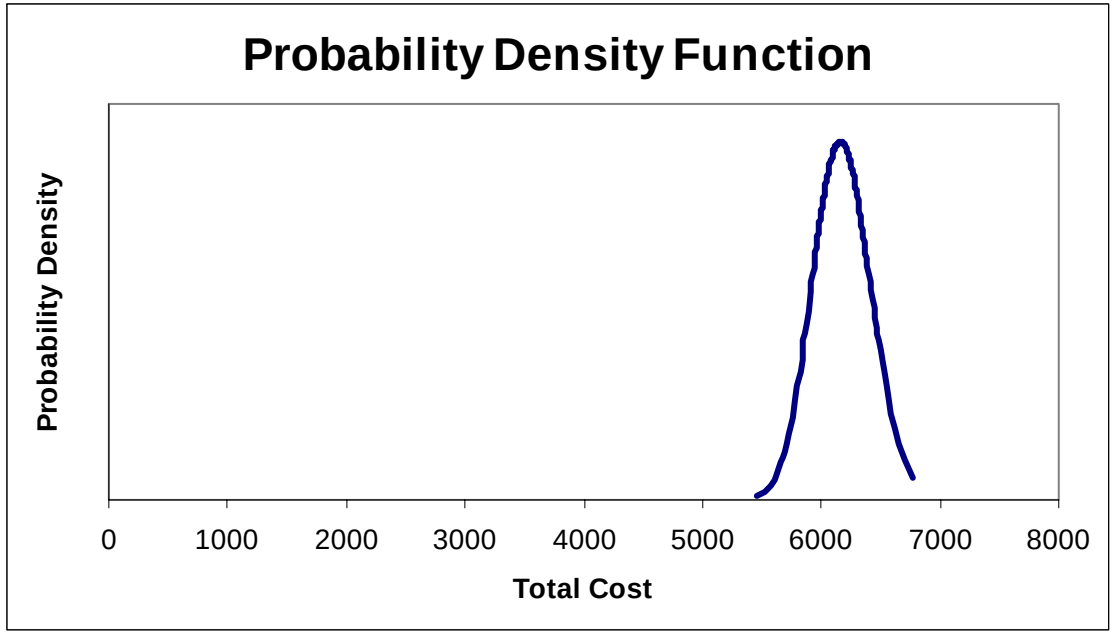
Correlation Matrix: Edit Lower-Traingular Portion

NAME	L	ML	H	WBS 1	WBS 2	WBS 3
1.3.17.1	2387.3	2802.1	3154.7	1		
1.3.17.3	2984.3	3132.9	3410.89	1	1	
1.3.17.5	218.5	218.5	220.685	1	1	1

$	6,177	Mean (Expected Cost)
$	6,172	Median (50th percentile)
$	6,162	Mode (Most Likely)
$	246	Std. Deviation

Confidence Percentiles

$	5,781	5%
$	5,865	10%
$	5,923	15%
$	5,969	20%
$	6,008	25%
$	6,044	30%
$	6,078	35%
$	6,110	40%
$	6,141	45%
$	6,172	50%
$	6,203	55%
$	6,234	60%
$	6,267	65%
$	6,302	70%
$	6,340	75%
$	6,382	80%
$	6,431	85%
$	6,494	90%
$	6,589	95%



Non Critical Path Integration Points – MP

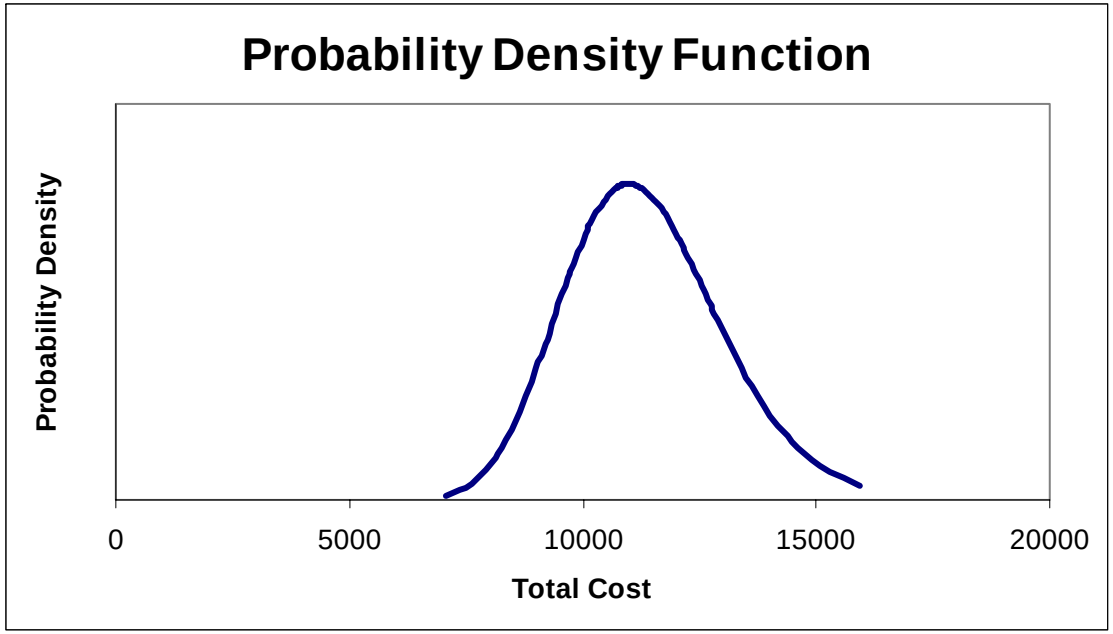
Correlation Matrix: Edit Lower-Traingular Portion

NAME	L	ML	H	WBS 1	WBS 2	WBS 3	WBS 4
1.3.15.1	1067.1	1334.6	2390.4	1			
1.3.16.1	82.9	82.9	83.729	0.2	1		
series	1124	2831	6663	1	0.2	1	
parallel	5458	6209	6770	1	0.2	1	1

$ 11,366 Mean (Expected Cost)
$ 11,239 Median (50th percentile)
$ 10,989 Mode (Most Likely)
$ 1,712 Std. Deviation

Confidence Percentiles

$ 8,784	5%
$ 9,275	10%
$ 9,622	15%
$ 9,907	20%
$ 10,158	25%
$ 10,389	30%
$ 10,608	35%
$ 10,820	40%
$ 11,029	45%
$ 11,239	50%
$ 11,452	55%
$ 11,673	60%
$ 11,907	65%
$ 12,157	70%
$ 12,434	75%
$ 12,749	80%
$ 13,127	85%
$ 13,618	90%
$ 14,380	95%



Non Critical Path Integration Points – LP

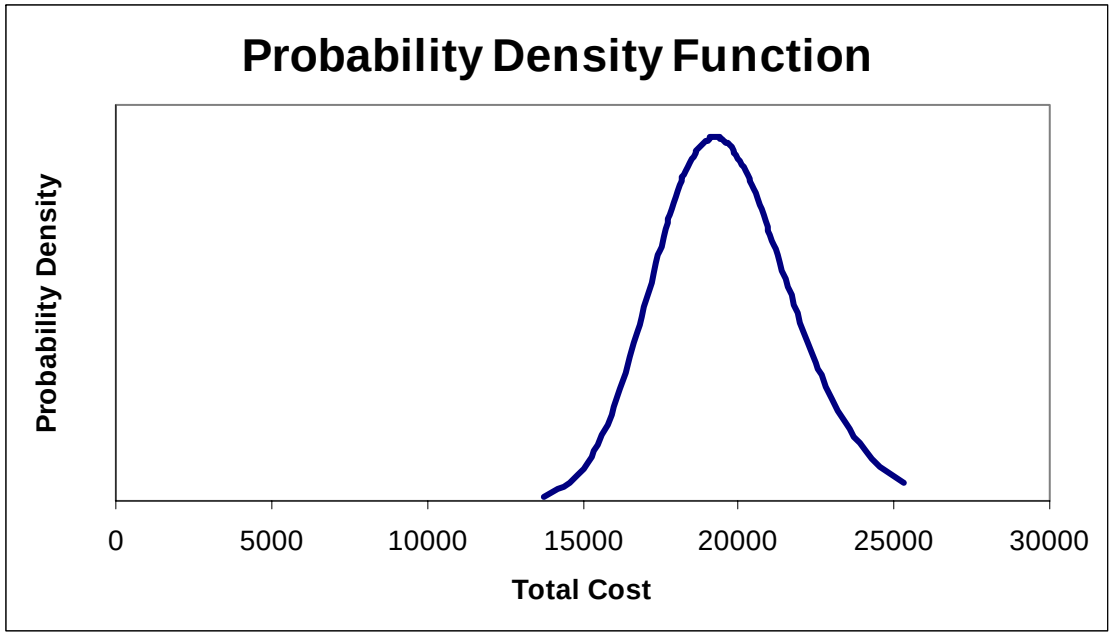
Correlation Matrix: Edit Lower-Traingular Portion

NAME	L	ML	H	WBS 1	WBS 2	WBS 3	WBS 4	WBS 5
1.3.2.1	829	829	837.29	1				
1.3.2.2	4554.8	5268.8	6971.09	0.2	1			
1.3.2.3	201.2	1558.2	1614.9	0.2	1	1		
1.3.2.4	0	1004.6	1004.6	0.2	0.2	0.2	1	
Middle Path	7074	11155	15925	0.2	0.2	0.2	0.2	1

$ 19,609	Mean (Expected Cost)
$ 19,486	Median (50th percentile)
$ 19,242	Mode (Most Likely)
$ 2,208	Std. Deviation

Confidence Percentiles

$ 16,200	5%
$ 16,875	10%
$ 17,346	15%
$ 17,729	20%
$ 18,065	25%
$ 18,372	30%
$ 18,661	35%
$ 18,940	40%
$ 19,213	45%
$ 19,486	50%
$ 19,763	55%
$ 20,048	60%
$ 20,347	65%
$ 20,668	70%
$ 21,019	75%
$ 21,417	80%
$ 21,890	85%
$ 22,501	90%
$ 23,438	95%



Critical Path Integration Points – END

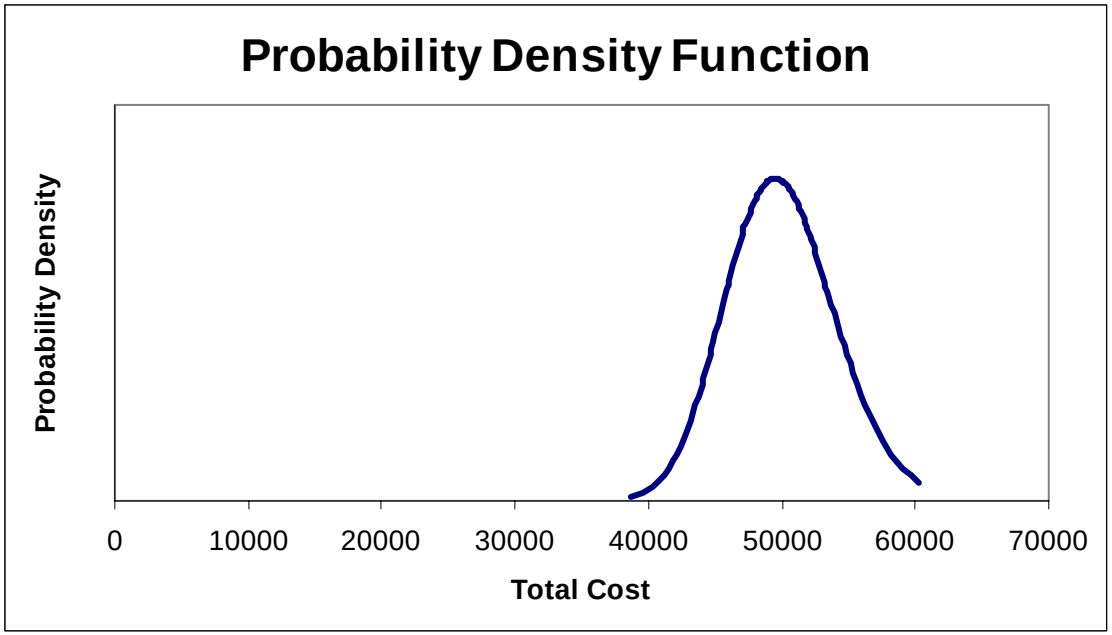
Correlation Matrix: Edit Lower-Traingular Portion

NAME	L	ML	H	WBS 1	WBS 2	WBS 3
Critical Path 2	18460	24060	29261	1		
1.3.11	4760.36	6536.2	8344.4	1	1	
Lower Path	13774	19486	25302	0.2	0.2	1

$ 49,995	Mean (Expected Cost)
$ 49,826	Median (50th percentile)
$ 49,491	Mode (Most Likely)
$ 4,114	Std. Deviation

Confidence Percentiles

$ 43,528	5%
$ 44,847	10%
$ 45,759	15%
$ 46,497	20%
$ 47,140	25%
$ 47,725	30%
$ 48,274	35%
$ 48,800	40%
$ 49,314	45%
$ 49,826	50%
$ 50,343	55%
$ 50,874	60%
$ 51,429	65%
$ 52,020	70%
$ 52,665	75%
$ 53,393	80%
$ 54,255	85%
$ 55,358	90%
$ 57,035	95%

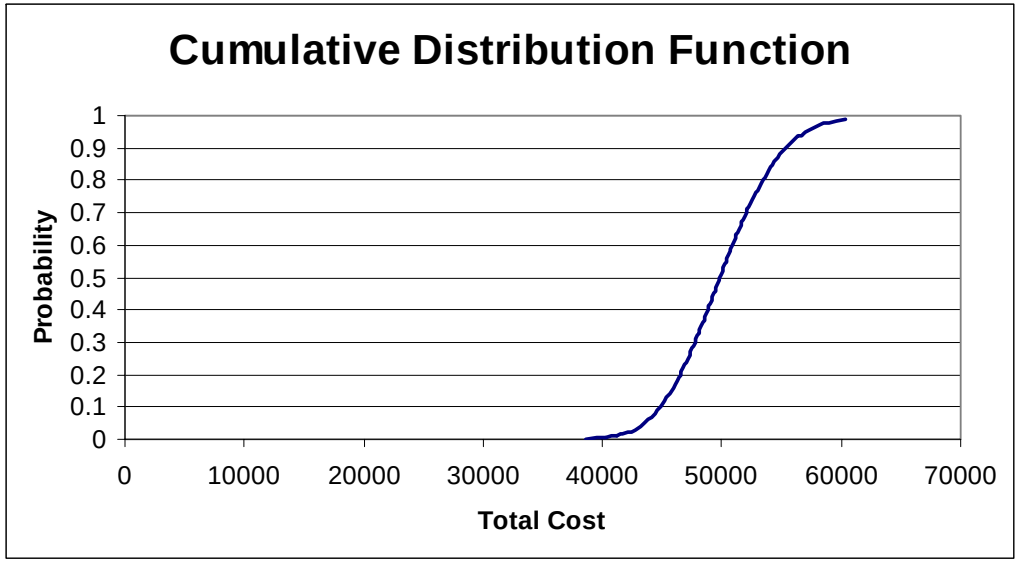


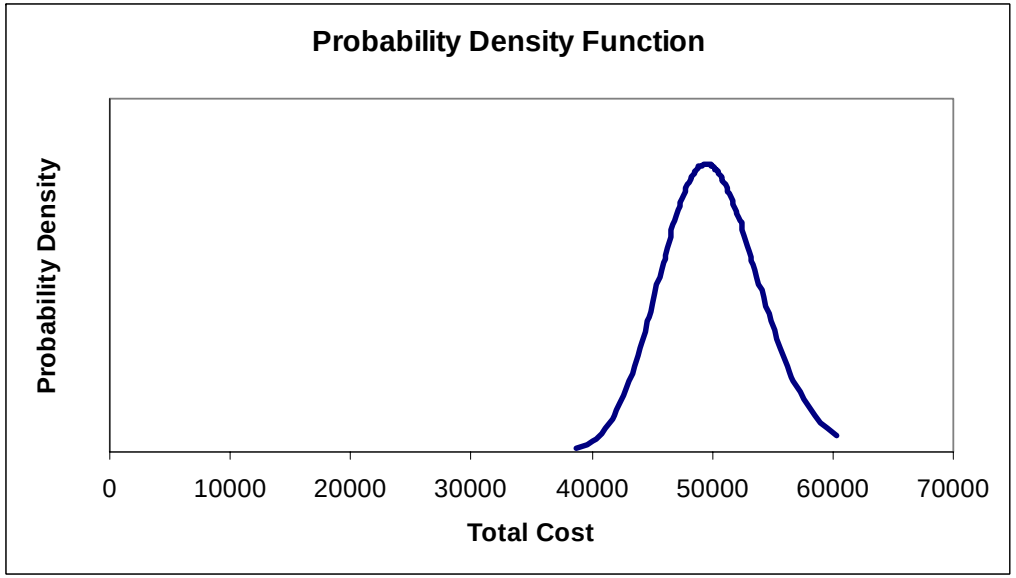
Results of Correlated Sum With Causal Paths

$ 49,995	Mean (Expected Cost)
$ 49,826	Median (50th percentile)
$ 49,491	Mode (Most Likely)
$ 4,114	Std. Deviation

Confidence Percentiles

$ 43,528	5%
$ 44,847	10%
$ 45,759	15%
$ 46,497	20%
$ 47,140	25%
$ 47,725	30%
$ 48,274	35%
$ 48,800	40%
$ 49,314	45%
$ 49,826	50%
$ 50,343	55%
$ 50,874	60%
$ 51,429	65%
$ 52,020	70%
$ 52,665	75%
$ 53,393	80%
$ 54,255	85%
$ 55,358	90%
$ 57,035	95%

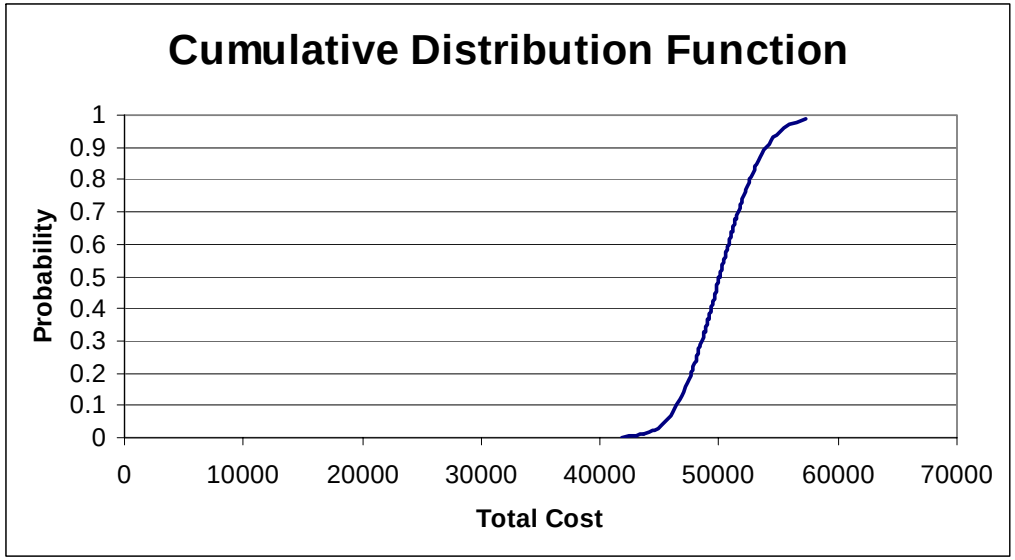


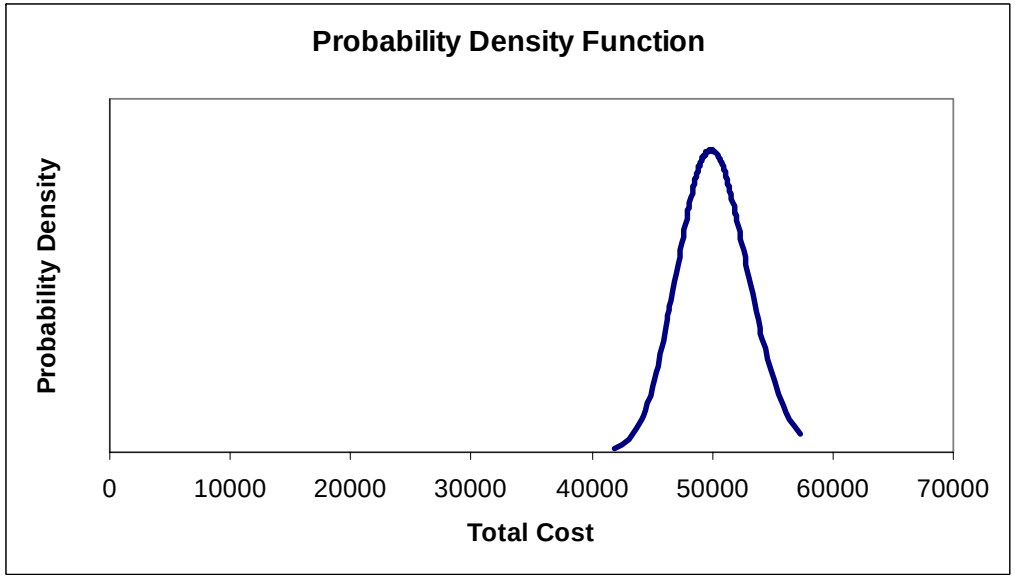


Results of 0.2 Default
Correlated Sum Without Causal Paths

$ 50,156 Mean (Expected Cost)
$ 50,071 Median (50th percentile)
$ 49,901 Mode (Most Likely)
$ 2,931 Std. Deviation

Confidence	Percenti
$ 45,486	5%
$ 46,461	10%
$ 47,131	15%
$ 47,670	20%
$ 48,137	25%
$ 48,561	30%
$ 48,957	35%
$ 49,336	40%
$ 49,705	45%
$ 50,071	50%
$ 50,440	55%
$ 50,817	60%
$ 51,210	65%
$ 51,628	70%
$ 52,082	75%
$ 52,593	80%
$ 53,195	85%
$ 53,962	90%
$ 55,118	95%





Comparison

Statistical Sum Without Causal Paths

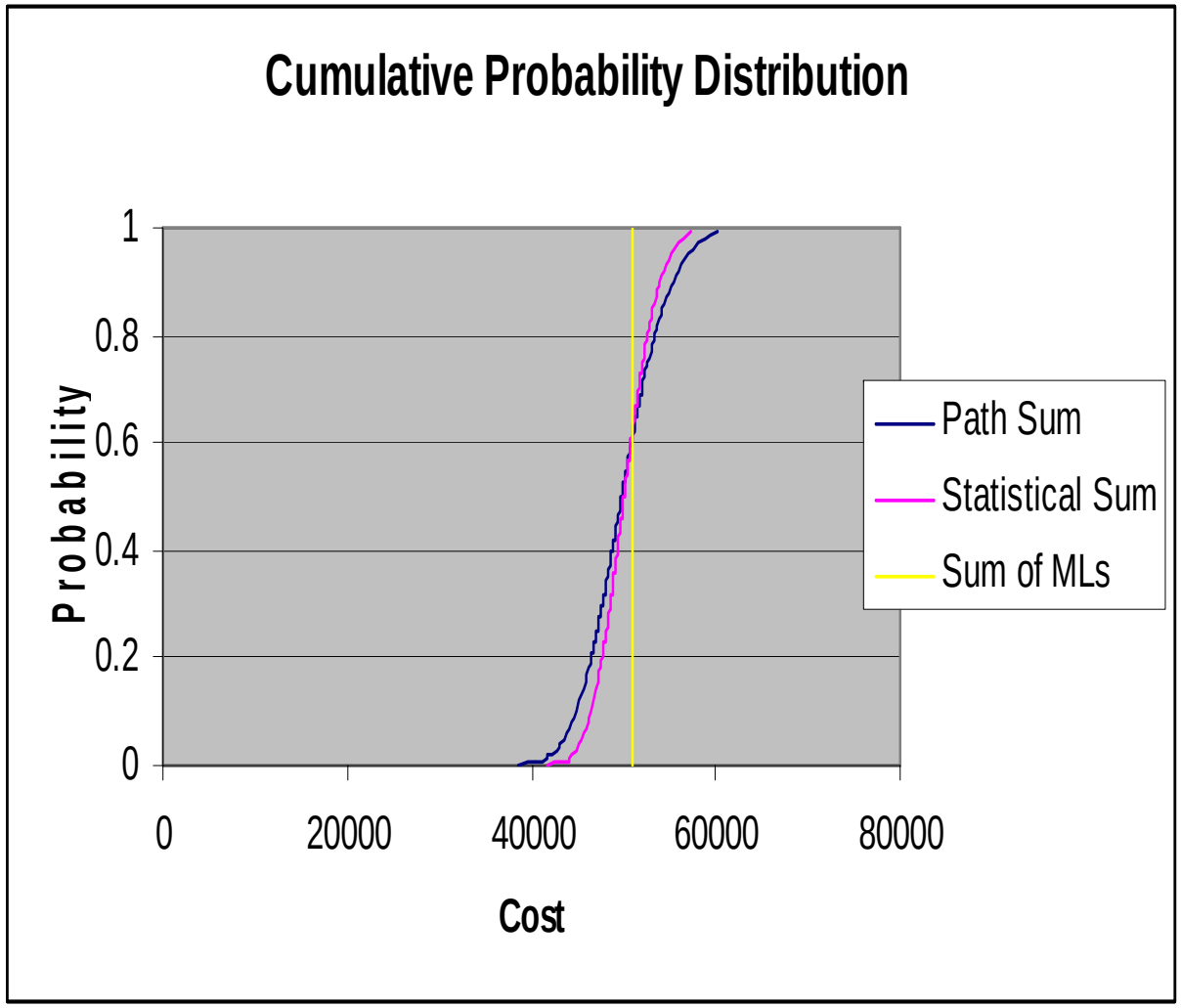
$ 50,156 Mean (Expected Cost)
$ 50,071 Median (50th percentile)
$ 49,901 Mode (Most Likely)
$ 2,931 Std. Deviation

Statistical Sum With Causal Paths

$ 49,995 Mean (Expected Cost)
$ 49,826 Median (50th percentile)
$ 49,491 Mode (Most Likely)
$ 4,114 Std. Deviation

Causal Path Sum Gives ~33% More Risk

Sum of MLs Gives Zero Risk, Always wrong: 50896



Summary of the Day

- Intro to EVM/Evolving Policy
- 1st Soupçon of Statistics
- Scheduling and Risk Analysis
- 2nd Soupçon of Statistics
- Estimates part 1
- Estimates part 2