Do Not Sum Earned-Value-Based WBS-Element Estimates-at-Completion

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EVMS Acronyms

- ACWP = Actual Cost of Work Performed (“the cost”)
- BAC = Budget at Completion (Total Program Budget)
- BAC-$ACWP_{cum}$ = Actual Remaining Budget
- BAC-$BCWP_{cum}$ = Budgeted Cost of Remaining Work
- BCWP = Budgeted Cost of Work Performed (“the value”)
- BCWS = Budgeted Cost of Work Scheduled (“the plan”)
- “cum” = Cumulative (beginning of program until now)
- EAC = Estimate at Completion
- EVMS = Earned-Value-Management System
- LRE = Latest Revised (Contractor-Produced) Estimate
  - Not Necessarily Derived from EVMS Data
- PF = Performance Factor
- WBS = Work-Breakdown Structure

Contents

- **The "Estimate at Completion" – What Does it Mean?**
- **Rolling Up the Work-Breakdown Structure (WBS)**
- **A Statistical Model of EAC Risk**
- **Summary**

Cost Performance Report
31 December 1999

Item	Cumulative To Date					At Completion		
	Budgeted Cost		Actual	Variance				
	of Work Scheduled	of Work Performed	Cost of Work Performed	Schedule	Cost	Budget	Latest Revised Estimate	Variance
1.0 System	51,019	49,884	53,789	-1,135	-3,905	94,355	98,607	-4,252
2.0 Adjunct Integration and Test	94	92	74	-2	18	4,606	4,583	23
3.0 Mission Operations	14,573	14,573	14,392	0	181	36,034	36,003	31
4.0 Project Management	8,047	8,177	9,909	130	-1,732	14,581	16,464	-1,883
5.0 System Engineering	13,026	12,765	16,198	-261	-3,433	25,524	29,045	-3,521
Overhead and G&A	3,226	3,198	2,628	-28	570	8,019	6,938	1,081
Undistributed Budget						228	228	
Subtotal	89,985	88,689	96,990	-1,296	-8,301	183,347	191,868	-8,521
Management Reserve								
Total	89,985	88,689	96,990	-1,296	-8,301	183,347	191,868	-8,521

Note: Dollars in Thousands

"Point" EAC Estimates

- **Funding Organizations and Program Managers Seek Point EACs for Budget Planning**
- **But Program Cost is a Nebulous Quantity, Heavily Impacted by**
  - **Technological (im)maturity**
  - **Programmatic Considerations**
  - **"Normal" Schedule Slips**
  - **Unforeseen Events**
- **Point EACs Cannot be "Correct" Because**
  - **Every Work-Breakdown-Structure (WBS) Element Contains Uncertainty**
  - **Total System Cost is Sum of These WBS Elements**
- **"Actual" Program Cost Falls within a Range Surrounding the "Best" Estimate (with some degree of confidence)**
  - **Program Control Requires Program Management Insight into Probabilities of Cost Overruns of Various Magnitudes**
  - **The Best We Can Hope to Do is to Understand the Uncertainty**

Typical EAC "Roll-Up" Procedure

- **List Cost Elements in a Work-Breakdown Structure (WBS)**
- **Calculate Point EAC for Each WBS Element**
- **Sum All Point EACs**
- **Define Result to be Point EAC of Total System**

What is an EAC?

- **Mathematically, an EAC is a Sum of Two Quantities**
  - **Total Expenditures on the Program Up to Now**
  - **Estimated Cost of Remaining Work**
- **"Total Expenditures on the Program Up to Now" is a Fixed Number - We Know What It Is**
- **"Estimated Cost of Remaining Work" is Uncertain - This is What has to be Estimated**

Can We Derive an EAC from Earned-Value Data?

- **Yes, If We Believe that "What's Past is Prologue"** *(Shakespeare, The Tempest, Act II, Scene 1)*
- **Use Earned-Value Data to Calculate a Metric that Measures Program Performance Up to Now, e.g., a "Performance Factor" such as**
  - **Cost Performance Index (CPI)**
  - **Schedule Performance Index (SPI)**
  - **Weighted Average of CPI and SPI**
  - **Schedule-Cost Index (SCI = SPI ^{x} CPI)**
- **Apply "Performance Factor" to Project Past Performance Forward**

Performance Factor Details

- **Converts Budgeted Cost of Remaining Work into Estimate of Actual Cost of Remaining Work**
- **EVMS-derived Performance Factors (PFs)**
  - **Cost Performance Index (CPI)**
  - **Schedule Performance Index (SPI)**
  - **Combination of CPI and SPI, e.g.,**
    - **Weighted Average: WTAVG = wCPI + (1-w)SPI, where 0 < w < 1**
    - **Product: SCI = CPI x SPI**
- **CPI = BCWP/ACWP**
  - **CPI < 1 if There is a Cost Overrun on Work Performed**
  - **CPI > 1 if There is a Cost Underrun on Work Performed**
- **SPI = BCWP/BCWS**
  - **SPI < 1 if the Dollar Value of Work Performed is Less than the Dollar Value of Work Scheduled (An "Accomplishment Deficit")**
  - **SPI > 1 if the Dollar Value of Work Performed Exceeds the Dollar Value of Work Scheduled (An "Accomplishment Surplus")**

EAC Formula via EVMS Acronyms

- **$ACWP_{cum}$ = Actual Cost of Work Performed, Cumulative from Start of Program**
- **BAC = "Budget at Completion", namely Total Program Budget**
- **$BCWP_{cum}$ = Budgeted Cost of Work Performed from Start of Program (Dollar Value of Work Accomplished Up to Now)**
- **BAC - $BCWP_{cum}$ = Budget Remaining to Complete the Program**
- **PF = Performance Factor**
- **(BAC - $BCWP_{cum}$)/PF = Remaining Budget Projected Forward to Program Completion**
- **EAC = $ACWP_{cum}$ + [(BAC - $BCWP_{cum}$)/PF]**

So How do We Calculate the EAC?

- **Excuse Me, but You Really Mean the *EACs*, Don't You?**
- **Of Course You Do, Because You are Entitled to One EAC per Performance Factor per WBS Element**
- **EACs Derived Using Different Performance Factors are Different**
- **How Many EACs are There? Well, That Depends on How Many Performance Factors There Are!**
- **How Many Possible Performance Factors are There?**
  - **I Forgot, but You Don't Want to Know Anyway!**
  - **But Today We'll Work with Four of Them**

Cost Performance Report
31 December 1999

Item	Cumulative To Date					At Completion		
	Budgeted Cost		Actual	Variance				
	of Work Scheduled	of Work Performed	Cost of Work Performed	Schedule	Cost	Budget	Latest Revised Estimate	Variance
1.0 System	51,019	49,884	53,789	-1,135	-3,905	94,355	98,607	-4,252
2.0 Adjunct Integration and Test	94	92	74	-2	18	4,606	4,583	23
3.0 Mission Operations	14,573	14,573	14,392	0	181	36,034	36,003	31
4.0 Project Management	8,047	8,177	9,909	130	-1,732	14,581	16,464	-1,883
5.0 System Engineering	13,026	12,765	16,198	-261	-3,433	25,524	29,045	-3,521
Overhead and G&A	3,226	3,198	2,628	-28	570	8,019	6,938	1,081
Undistributed Budget						228	228	
Subtotal	89,985	88,689	96,990	-1,296	-8,301	183,347	191,868	-8,521
Management Reserve								
Total	89,985	88,689	96,990	-1,296	-8,301	183,347	191,868	-8,521

Note: Dollars in Thousands

Performance Factors Derived From Cost Performance Report

WBS Item	CPI = BCWP/ACWP	SPI = BCWP/BCWS	WTAVG = 0.8CPI+0.2SPI	SCI = SPIxCPI
1.0	0.9274	0.9778	0.9375	0.9068
2.0	1.2432	0.9787	1.1903	1.2167
3.0	1.0126	1.0000	1.0101	1.0126
4.0	0.8252	1.0162	0.8634	0.8386
5.0	0.7881	0.9800	0.8265	0.7723
OV,G&A	1.2169	0.9913	1.1718	1.2063
Total	0.9144	0.9856	0.9286	0.9012

NOTE: When referring to earned-value performance factors on this and upcoming tables, "Total" refers to factors calculated on the basis of total-program data, NOT to the sums of the various columns of the table.

WBS-Item vs. Total-Program EACs
(Performance Factor = CPI)

WBS Item	BCWS	BCWP	ACWP	PF = CPI	BAC	BAC - BCWP	÷ PF =	+ ACWP = EAC
1.0	51,019	49,884	53,789	0.9274	94,355	44,471	44,952	101,741
2.0	94	92	74	1.2432	4,606	4,514	3,631	3,705
3.0	14,573	14,573	14,392	1.0126	36,034	21,461	21,194	35,586
4.0	8,047	8,177	9,909	0.8252	14,581	6,404	7,760	17,669
5.0	13,026	12,765	16,198	0.7881	25,524	12,759	16,190	32,388
OV,G&A	3,226	3,198	2,628	1.2169	8,019	4,821	3,962	6,590
Total Program	89,985	88,689	96,990	0.9144	183,119	94,430	103,270	200,260

NOTES: (1) UNDISTRIBUTED MANAGEMENT RESERVE IS NOT INCLUDED IN "TOTAL".
(2) SUM OF WBS ITEMS' EACs = 197,679, LESS THAN TOTAL PROGRAM'S 200,260.

WBS-Item vs. Total-Program EACs
(Performance Factor = SPI)

WBS Item	BCWS	BCWP	ACWP	PF = SPI	BAC	BAC - BCWP	÷ PF =	+ ACWP = EAC
1.0	51,019	49,884	53,789	0.9778	94,355	44,471	45,483	99,272
2.0	94	92	74	0.9787	4,606	4,514	4,612	4,686
3.0	14,573	14,573	14,392	1.0000	36,034	21,461	21,461	35,853
4.0	8,047	8,177	9,909	1.0162	14,581	6,404	6,302	16,211
5.0	13,026	12,765	16,198	0.9800	25,524	12,759	13,020	29,218
OV,G&A	3,226	3,198	2,628	0.9913	8,019	4,821	4,863	7,491
Total Program	89,985	88,689	96,990	0.9856	183,119	94,430	95,810	192,800

NOTES: (1) UNDISTRIBUTED MANAGEMENT RESERVE IS NOT INCLUDED IN "TOTAL".
(2) SUM OF WBS ITEMS' EACs = 192,731, LESS THAN TOTAL PROGRAM'S 192,800.

WBS-Item vs. Total-Program EACs
(Performance Factor = WTAVG)

WBS Item	BCWS	BCWP	ACWP	PF = WTAVG	BAC	BAC - BCWP	÷ PF =	+ ACWP = EAC
1.0	51,019	49,884	53,789	0.9375	94,355	44,471	47,437	101,226
2.0	94	92	74	1.1903	4,606	4,514	3,792	3,866
3.0	14,573	14,573	14,392	1.0101	36,034	21,461	21,247	35,639
4.0	8,047	8,177	9,909	0.8634	14,581	6,404	7,417	17,326
5.0	13,026	12,765	16,198	0.8256	25,524	12,759	15,438	31,636
OV,G&A	3,226	3,198	2,628	1.1718	8,019	4,821	4,114	6,742
Total Program	89,985	88,689	96,990	0.9286	183,119	94,430	101,691	198,681

WTAVG = 0.80 CPI + 0.20 SPI

NOTES: (1) UNDISTRIBUTED MANAGEMENT RESERVE IS NOT INCLUDED IN "TOTAL".
(2) SUM OF WBS ITEMS' EACs = 196,435, LESS THAN TOTAL PROGRAM'S 198,681.

WBS-Item vs. Total-Program EACs
(Performance Factor = SCI)

WBS Item	BCWS	BCWP	ACWP	PF = SCI	BAC	BAC - BCWP	÷ PF =	+ ACWP = EAC
1.0	51,019	49,884	53,789	0.9068	94,355	44,471	49,042	102,831
2.0	94	92	74	1.2167	4,606	4,514	3,710	3,784
3.0	14,573	14,573	14,392	1.0126	36,034	21,461	21,194	35,586
4.0	8,047	8,177	9,909	0.8386	14,581	6,404	7,637	17,546
5.0	13,026	12,765	16,198	0.7723	25,524	12,759	16,521	32,719
OV,G&A	3,226	3,198	2,628	1.2063	8,019	4,821	3,997	6,625
Total Program	89,985	88,689	96,990	0.9012	183,119	94,430	104,783	201,773

NOTES: (1) UNDISTRIBUTED MANAGEMENT RESERVE IS NOT INCLUDED IN "TOTAL".
(2) SUM OF WBS ITEMS' EACs = 199,091, LESS THAN TOTAL PROGRAM'S 201,773.

Is Roll-Up Procedure Valid?

No!

Do Not Sum WBS-Element EACs Because ...

- **It Is a Mathematically Incorrect Procedure**
- **The Number You Get Does Not Mean What You Think It Means**
- **You Will Misestimate the Total System EAC**
  - **On Previous Charts, Sum of WBS-Element EACs Turned Out in Every Case to be Less than Total-Program EAC**
  - **It is not Known* Whether or Not There is a General Rule about This - All We Know for Sure is that the Sum of WBS-Element EACs and the Total-Program EAC are Different**
  - **Here is a Research Opportunity for You!**

*** By me.**

D.S. Christensen's Research

- **Current State of the Art in Using Earned-Value Information to Estimate Program Cost-at-Completion**
- **Available in Tutorial Entitled "Evaluating the Accuracy of the Estimate at Completion"Presented to**
  - **DoD Cost Analysis Symposium, Williamsburg, VA, 2-5 February 1999**
  - **ISPA/SCEA Joint National Conference, San Antonio, TX, 8-11 June 1999**
- **Major Conclusions (as far as our discussion today is concerned):**

DOD Experience

- ***CPI-based EAC is the floor to the actual final cost.***
- ***SCI-based EAC is often the most accurate estimate.***

(D.S. Christensen, "Project Advocacy and the EAC Problem," Journal of Cost Analysis, Spring 1996, pages 35-60)

Why Doesn't Summing Work?

- **When We Sum Numbers, We are Implicitly Assuming that Those Numbers are Deterministic and Precise**
- **But Each WBS-Element EAC is Actually a Random Variable whose Possible Values Range over an Interval Stretching at Least from the CPI-Based EAC to the SCI-Based EAC (*Viz.,* D.S. Christensen Research)**
  - **Where Within that Range the Actual EAC Will Fall Depends on Future Behavior that We Understand only with Great Uncertainty**
  - **The Numbers Printed in the Previous Tables are Really only Representatives of What the WBS-Element EACs *Could* Be**
- **We Should Therefore Do the Summing *Statistically* (by Monte Carlo), Rather than *Arithmetically* (by Adding)**

How Should We Do EAC Estimates?

- **Treat Every EAC Estimating Task As a Cost-Risk Analysis**
  - **Recognize Uncertainty Inherent in WBS-Element EACs**
  - **Construct Cost-at-Completion Probability Distribution for Each WBS Element**
- **Sum WBS-Element Costs-at-Completion Statistically (Via Monte-Carlo or Analytic Approximation)**
  - **Avoid Meaningless Outcome of Roll-up Procedure**
  - **Get Mean, Median, Mode of Total-System Cost at Completion**
  - **Get All Cost-at-Completion Percentiles as Products of a Cost-Risk Analysis**

What Does the Point EAC Mean?

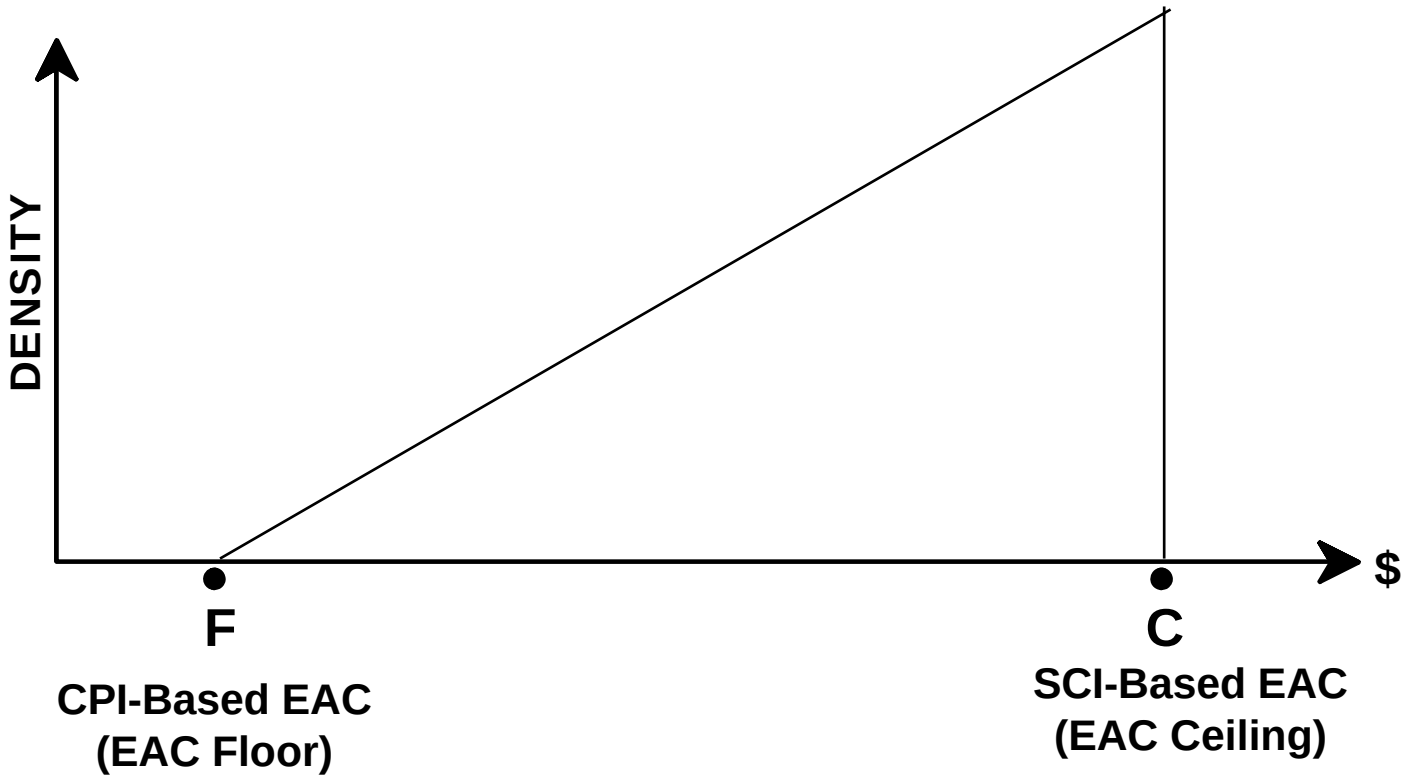
- **Is It the "Most Likely" Cost at Completion? ("Mode")**
- **Is It the 50th-Percentile Cost at Completion? ("Median")**
- **Is It the "Average" Cost at Completion? ("Mean")**
- **These Three Numbers are Almost Always Different**

Probability Distribution of the Cost-at-Completion

- There is a Whole Range of Possible EACs
- Mean, Median, Mode are Statistical Characteristics of Probability Distributions
- Use of These Terms Implicitly Assumes that Cost at Completion Has a Probability Distribution
- Indeed, Even Admission that the Point (or "most likely") EAC is Not the Only Possible EAC Implicitly Assumes that Other EACs are "Less Likely"
- This Discussion Leads Inexorably to Conclusion That Cost-at-Completion Has a Probability Distribution

Right-Triangular Distribution of Total-Program Cost-to-Complete

(inferred from D.S. Christensen research)

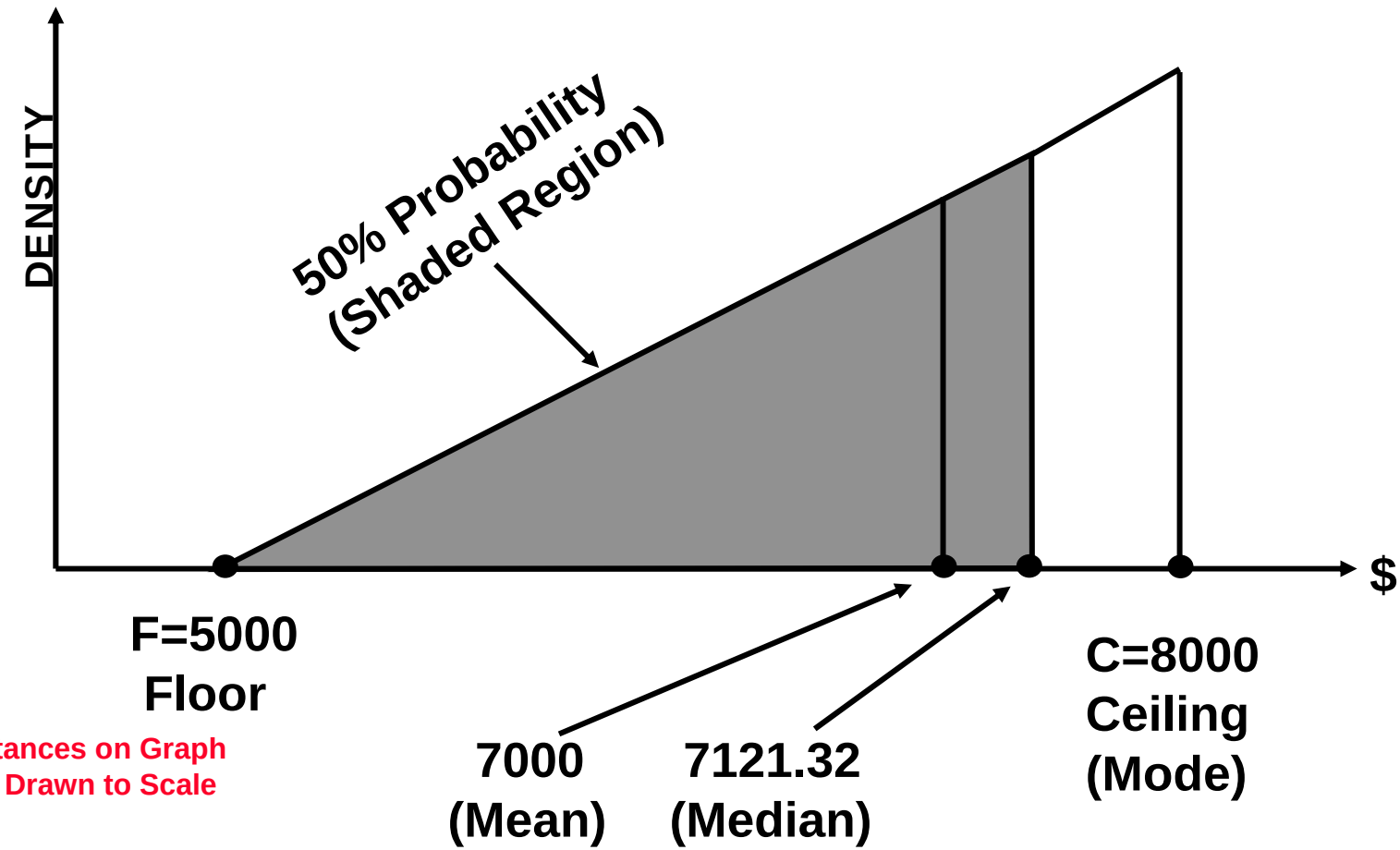


Statistical Descriptors of Right-Triangular Distributions

- **Parameters: F = EAC Floor, C = EAC Ceiling**
- **Mean EAC =** $\frac{F + 2C}{3}$
- **Median EAC =** $\frac{(\sqrt{2} - 1)F + C}{\sqrt{2}}$
- **Mode (Most Likely EAC) =** C **(based on AF experience)**
- **Standard Deviation (sigma value) =** $\frac{C - F}{3\sqrt{2}}$
- T_p **= pth Percentile EAC (i.e., P{EAC ≤** T_p**} = p)**

  $= (1 - \sqrt{p})F + \sqrt{p}C$

Example of Triangular Cost-to-Complete Distribution

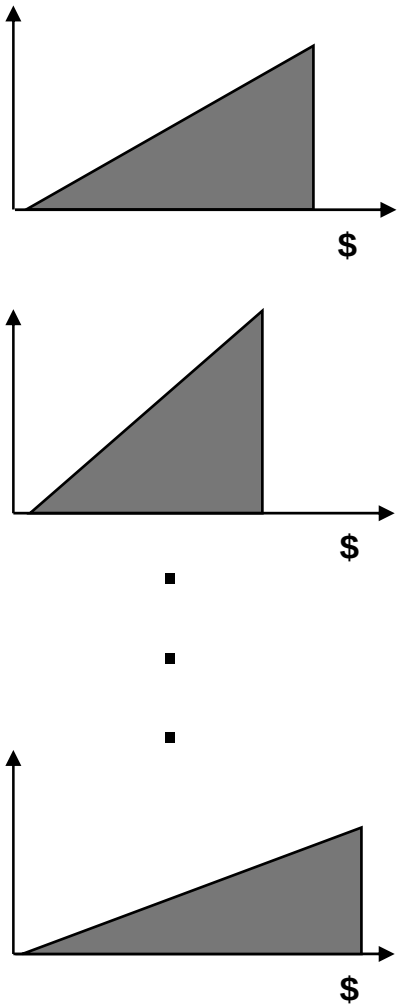


A Statistical Fact

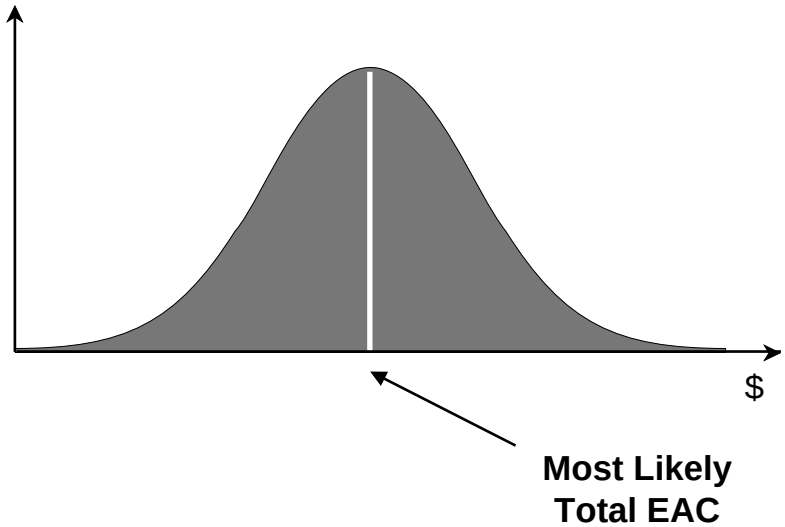
- **A Famous Theorem: "The Mean of a Sum of Statistical Quantities is Equal to the Sum of Their Individual Means"**
  - **If Number of WBS Elements is "Large," Distribution of Total Cost-to-Complete is Approximately Gaussian ("Central Limit Theorem")**
  - **But This Theorem is Valid Regardless of the Number of WBS Elements and Has Nothing to Do with the Gaussian Distribution**
  - **There is no Comparable Theorem that Applies to the Median or the Mode**
- **But for Large Number of WBS Elements Total Cost-to-Complete Distribution is Gaussian, so Mean=Median=Mode for Total**
  - **Total Cost-to-Complete Mean = Sum of WBS-Element Means**
  - **Total Cost-to-Complete Median = Sum of WBS-Element Means**
  - **Total Cost-to-Complete Mode = Sum of WBS-Element Means**
- **Therefore it Must be True that**
  - **Total Cost -to-Complete Median ≠ Sum of WBS-Element Medians**
  - **Total Cost -to-Complete Mode ≠ Sum of WBS-Element Modes**

When WBS Elements Are Many

WBS-Element Triangular EAC Distributions

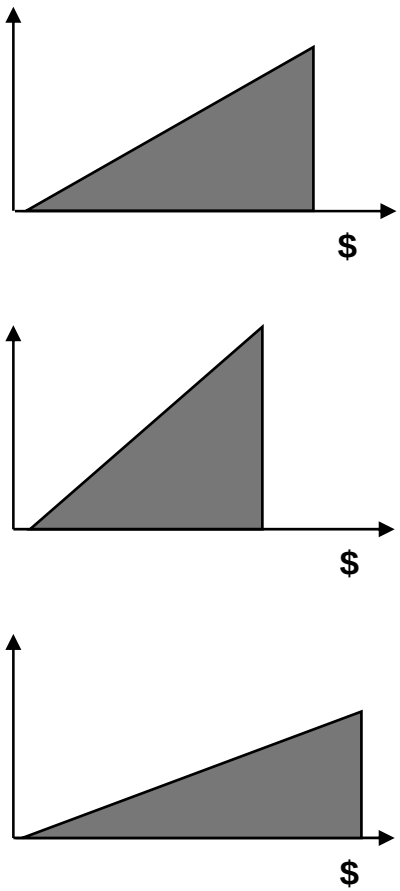


Merge WBS-Element EAC Distributions Into Total-EAC Gaussian Distribution

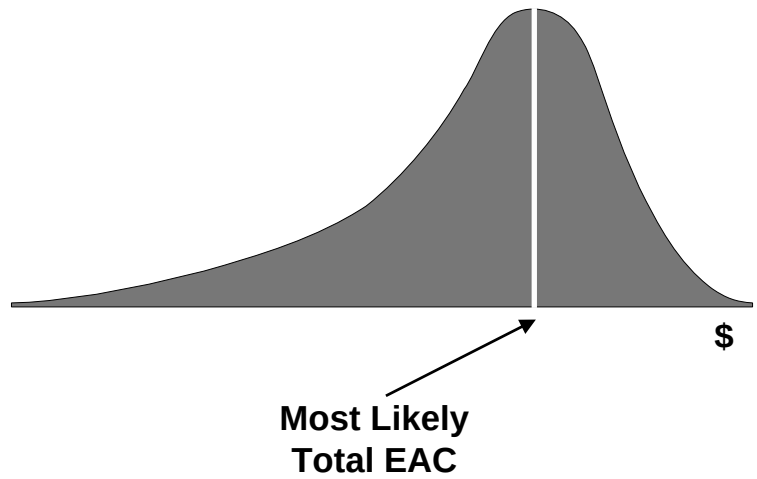


When WBS Elements Are Few

WBS-Element Triangular EAC Distributions



Merge WBS-Element EAC Distributions Into Total-EAC Skewed Distribution



EACs by Cost-Risk Methods

- **Construct Cost-at-Completion Probability Distribution for Each WBS Element**
  - **Use CPI-Based EACs as Lower Bounds**
  - **Use SCI-Based EACs as Upper Bounds**
- **Sum WBS-Element Costs-at-Completion Statistically (Via Monte-Carlo or Analytic Approximation)**
  - **Apply In-House-Developed Monte Carlo Tool or Commercial Software such as Crystal Ball™ or @Risk™**
  - **Obtain Mean, Median, Mode of Total-System Cost at Completion, as well as All Cost-at-Completion Percentiles, as Standard Outputs of Monte Carlo Software**

Additional Statistical Issues

- **We are Ignoring Inter-WBS-Element Correlation**
  - **EACs of WBS Elements are, in Fact, Correlated**
  - **Ignoring Correlation Makes the Probability Distribution of Total-Program EAC Narrower than it Really is**
  - **In any Actual EAC Analysis, Correlation Must be Taken into Consideration**
- **Is the Triangular Distribution the "Right" Model for *Every* WBS-Element EAC?**
  - **Maybe Not - Other Distributions, such as the Uniform, Gaussian, Lognormal, or Exponential, Might be Appropriate in Certain Cases**
  - **If Appropriate, Other Distributions Can be Handled without Undue Difficulty**

WBS-Item vs. Total-Program EACs
(Performance Factor = CPI)

WBS Item	BCWS	BCWP	ACWP	PF = CPI	BAC	BAC - BCWP	÷ PF =	+ ACWP = EAC
1.0	51,019	49,884	53,789	0.9274	94,355	44,471	44,952	101,741
2.0	94	92	74	1.2432	4,606	4,514	3,631	3,705
3.0	14,573	14,573	14,392	1.0126	36,034	21,461	21,194	35,586
4.0	8,047	8,177	9,909	0.8252	14,581	6,404	7,760	17,669
5.0	13,026	12,765	16,198	0.7881	25,524	12,759	16,190	32,388
OV,G&A	3,226	3,198	2,628	1.2169	8,019	4,821	3,962	6,590
Total Program	89,985	88,689	96,990	0.9144	183,119	94,430	103,270	200,260

NOTES: (1) UNDISTRIBUTED MANAGEMENT RESERVE IS NOT INCLUDED IN "TOTAL".
(2) SUM OF WBS ITEMS' EACs = 197,679, LESS THAN TOTAL PROGRAM'S 200,260.

WBS-Item vs. Total-Program EACs
(Performance Factor = Total-Program CPI)

WBS Item	BCWS	BCWP	ACWP	PF = T.P.CPI	BAC	BAC - BCWP	÷ PF =	+ ACWP = EAC
1.0	51,019	49,884	53,789	0.9144	94,355	44,471	48,634	102,423
2.0	94	92	74	0.9144	4,606	4,514	4,936	5,010
3.0	14,573	14,573	14,392	0.9144	36,034	21,461	23,470	37,862
4.0	8,047	8,177	9,909	0.9144	14,581	6,404	7,003	16,912
5.0	13,026	12,765	16,198	0.9144	25,524	12,759	13,953	30,151
OV,G&A	3,226	3,198	2,628	0.9144	8,019	4,821	5,272	7,900
Total Program	89,985	88,689	96,990	0.9144	183,119	94,430	103,270	200,260

NOTES: (1) UNDISTRIBUTED MANAGEMENT RESERVE IS NOT INCLUDED IN "TOTAL".
(2) SUM OF WBS ITEMS' EACs = 200,258, WITHIN ROUND-OFF DISTANCE OF TOTAL PROGRAM'S 200,260.

WBS-Item vs. Total-Program EACs
(Performance Factor = SCI)

WBS Item	BCWS	BCWP	ACWP	PF = SCI	BAC	BAC - BCWP	÷ PF =	+ ACWP = EAC
1.0	51,019	49,884	53,789	0.9068	94,355	44,471	49,042	102,831
2.0	94	92	74	1.2167	4,606	4,514	3,710	3,784
3.0	14,573	14,573	14,392	1.0126	36,034	21,461	21,194	35,586
4.0	8,047	8,177	9,909	0.8386	14,581	6,404	7,637	17,546
5.0	13,026	12,765	16,198	0.7723	25,524	12,759	16,521	32,719
OV,G&A	3,226	3,198	2,628	1.2063	8,019	4,821	3,997	6,625
Total Program	89,985	88,689	96,990	0.9012	183,119	94,430	104,783	201,773

NOTES: (1) UNDISTRIBUTED MANAGEMENT RESERVE IS NOT INCLUDED IN "TOTAL".
(2) SUM OF WBS ITEMS' EACs = 199,091, LESS THAN TOTAL PROGRAM'S 201,773.

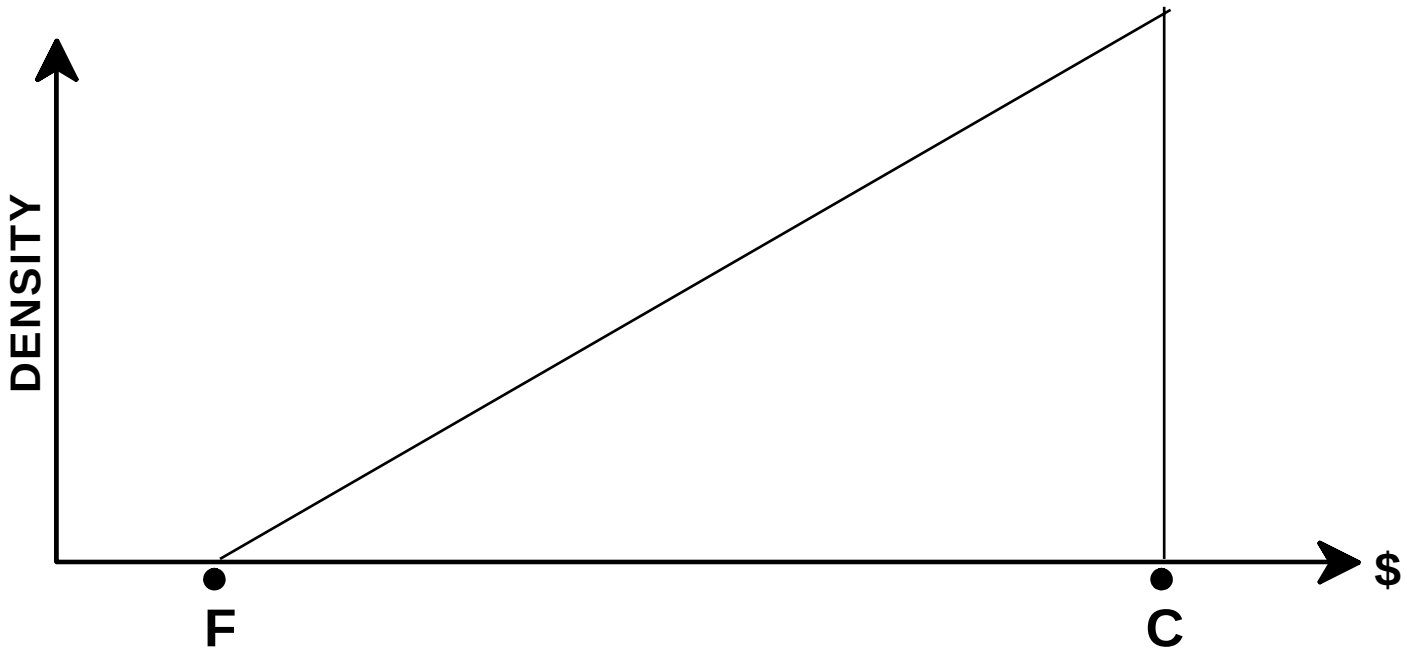
WBS-Item vs. Total-Program EACs
(Performance Factor = Total-Program SCI)

WBS Item	BCWS	BCWP	ACWP	PF = T.P.SCI	BAC	BAC - BCWP	÷ PF =	+ ACWP = EAC
1.0	51,019	49,884	53,789	0.9012	94,355	44,471	49,346	103,135
2.0	94	92	74	0.9012	4,606	4,514	5,009	5,083
3.0	14,573	14,573	14,392	0.9012	36,034	21,461	23,814	38,206
4.0	8,047	8,177	9,909	0.9012	14,581	6,404	7,106	17,015
5.0	13,026	12,765	16,198	0.9012	25,524	12,759	14,158	30,356
OV,G&A	3,226	3,198	2,628	0.9012	8,019	4,821	5,350	7,978
Total Program	89,985	88,689	96,990	0.9012	183,119	94,430	104,783	201,773

NOTES: (1) UNDISTRIBUTED MANAGEMENT RESERVE IS NOT INCLUDED IN "TOTAL".
(2) SUM OF WBS ITEMS' EACs = 201,773, THE SAME AS TOTAL PROGRAM'S 201,773.

Proposed Right-Triangular Distribution of WBS-Element Cost-to-Complete

(inferred from behavior of sample EV data)



EAC Floor = The smaller of

(1) Element CPI-based EAC

(2) Element T.P.CPI-based EAC

EAC Ceiling = The larger of

(1) Element SCI-based EAC

(2) Element T.P.SCI-based EAC

Crystal Ball™, @Risk™

- **Commercially Available Software Packages that are Add-ons to Additional Commercial Software Such As Windows, Excel, or Lotus on PC or Mac**
  - **Crystal Ball™ Marketed by Decisioneering, Inc., 2530 S. Parker Road, Suite 220, Aurora, CO 80014, (800) 289-2550**
  - **@Risk™ Marketed by Palisade Corporation, 31 Decker Road, Newfield, NY 14867, (800) 432-7475**
- **Inputs**
  - **Parameters Defining WBS-Element Distributions**
  - **Rank Correlations Among WBS-Element Cost Distributions**
- **Mathematics**
  - **Monte-Carlo and Stratified Random Sampling (Latin Hypercube)**
  - **Virtually All Probability Distributions That Have Names Can Be Used**
  - **Suggests Adjustments to Inconsistent Input Correlation Matrix**
- **Outputs**
  - **Percentiles of Program Cost**
  - **Cost Probability Density and Cumulative Distribution Graphics**

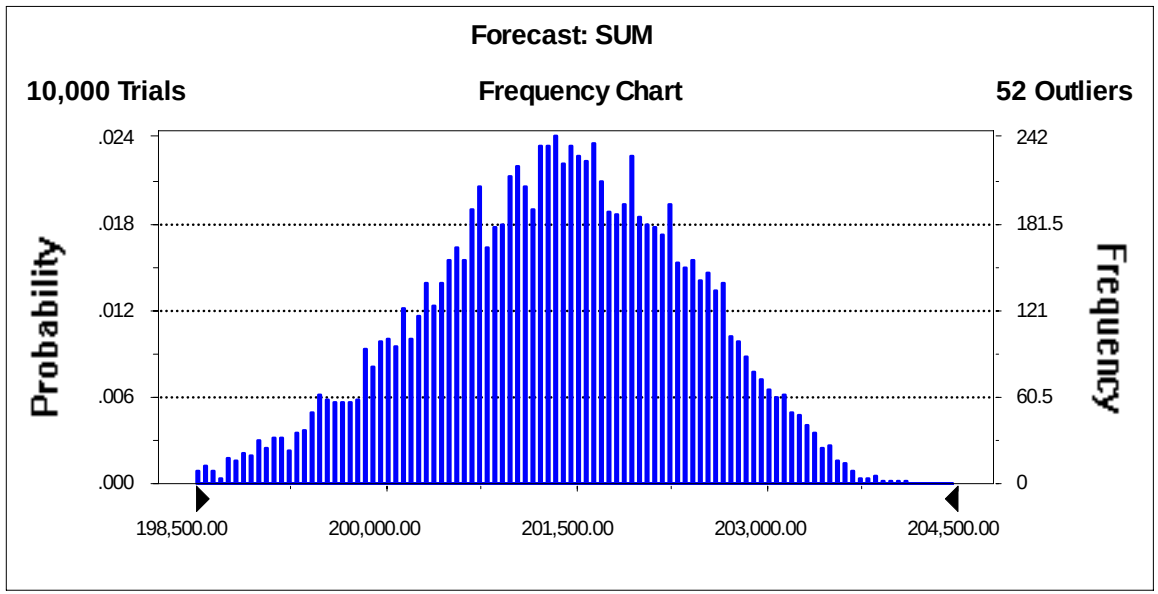
Inputs to Crystal Ball™ Monte Carlo Run

WBS Item	Low	Mode = High
1.0	101,741	103,135
2.0	3,705	5,083
3.0	35,586	38,206
4.0	16,912	17,546
5.0	30,151	32,719
OV,G&A	6,590	7,978

Crystal Ball™ Output Report

Crystal Ball Report
Simulation started on 4/25/00 at 16:32:45
Simulation stopped on 4/25/00 at 16:35:13

Forecast: SUM



Percentiles:

Percentile	Value
0%	197,346.26
10%	199,963.41
20%	200,476.34
30%	200,823.31
40%	201,122.53
50%	201,390.12
60%	201,651.04
70%	201,943.41
80%	202,265.61
90%	202,675.59
100%	204,127.73

Statistics of Sum of Six Uncorrelated EAC Right-Triangular Distributions

(Monte-Carlo Simulation Output from Crystal Ball™ Software)

Statistic	Dollar Value	Roll-Up Value
Standard Deviation	1,044	-
CPI-Based EAC	200,260	197,679
30th Percentile	200,823	-
Mean	201,348	201,341
Mode	201,375	-
50th Percentile (Median)	201,390	-
SCI-Based EAC	201,773	199,091
70th Percentile	201,943	-
90th Percentile	202,676	-

Discussion of Cost-Risk Output

- **CPI-Based EAC is Below the 30% Confidence Level (it's approximately at the 16% confidence level)**
- **SCI-Based EAC is Approximately at the 64% Confidence Level**
- **WBS-Element Roll-ups are, in Both Cases, Significantly Lower (5% and 8% confidence levels, respectively)**
- **Realistic Correlations between WBS-Elements EACs will Increase the Standard Deviation (sigma value) and Widen the Total-Program EAC Distribution**
  - **Below-the-Mean Values will be Smaller**
  - **Above-the-Mean Values will be Larger**

Summary

- **EACs are Random Variables, Not Deterministic Numbers, and Must be Handled Statistically**
  - **Avoid Meaningless, Contradictory Outcome of Roll-up Procedure**
  - **Get Mean, Median, Mode of Total-System Cost at Completion, as well as All Cost-at-Completion Percentiles**
- **EAC Uncertainty is Due to**
  - **Discrepancies Among CPI-, SPI-, WTAVG-, and SCI-Based Methods of Calculating EACs**
  - **Differences Between Total-Program EACs Calculated by Roll-up of WBS-Element EACs and Directly from Total-Program EV Data**
- **Coherent Theory Presented Here to Take These Facts into Account when Estimating Total-Program EAC**