



Integrating Cost & Schedule Risk Analyses: Creating Improved Resource Allocations

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Outline

- Objective
- Background
- Recommended Solution
- Path Forward to Standard Operating Procedure
- Expected Benefits



Objective

- Facilitate decision maker's ability to make optimal investment selections
 - Enable program level trade-offs between cost and schedule confidence
 - Evaluate joint impact of cost and schedule risk on program/alternative life-cycle cost
- Ensure cost and schedule estimates are based on a common technical baseline

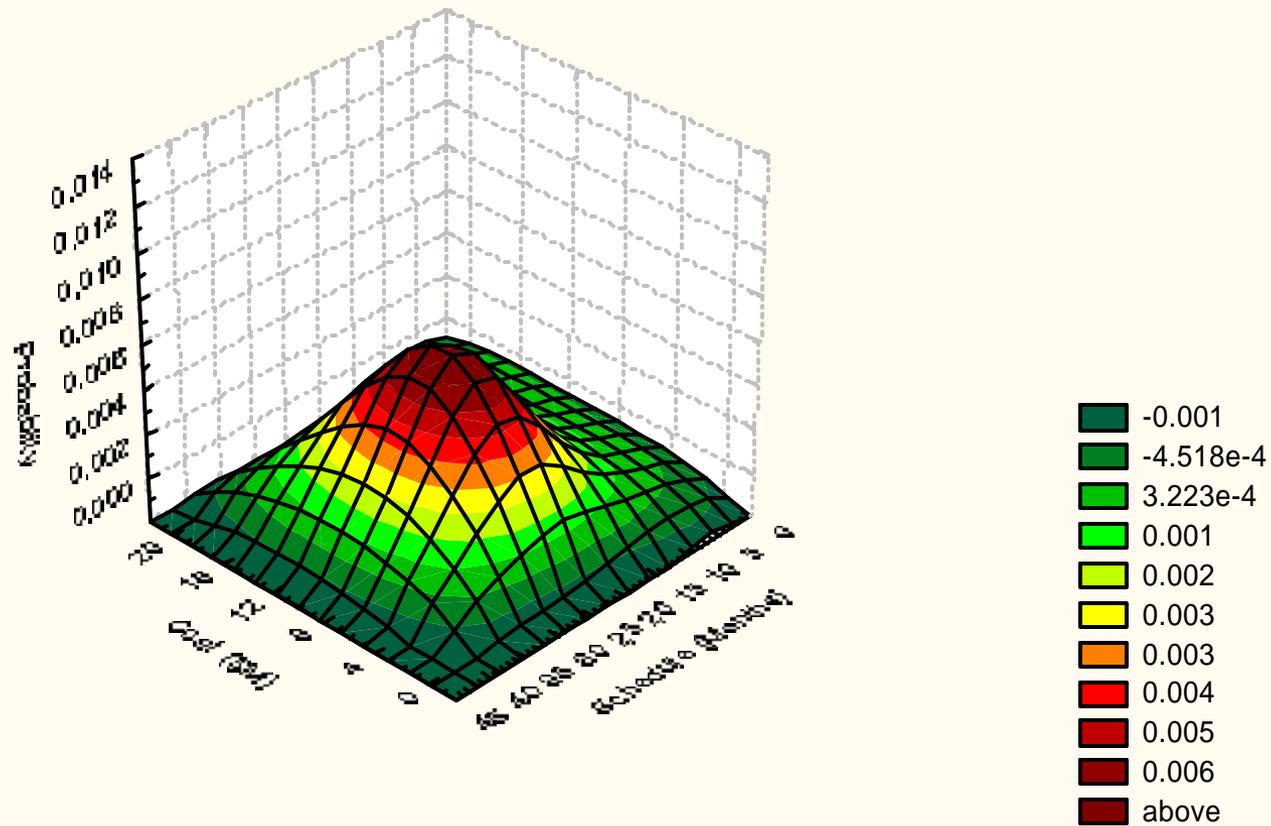


Background

- Garvey, P. R., 1996. “Modeling Cost and Scheduling Uncertainties - A Work Breakdown Structure Perspective,” *Military Operations Research*, V2, N1, pp. 37-43
 - Demonstrates how multivariate probability theory could be used to integrate univariate cost and schedule probability distributions
 - Uses joint distributions to develop a surface area
 - Uses conditional distributions to model “slices” of the joint distributions

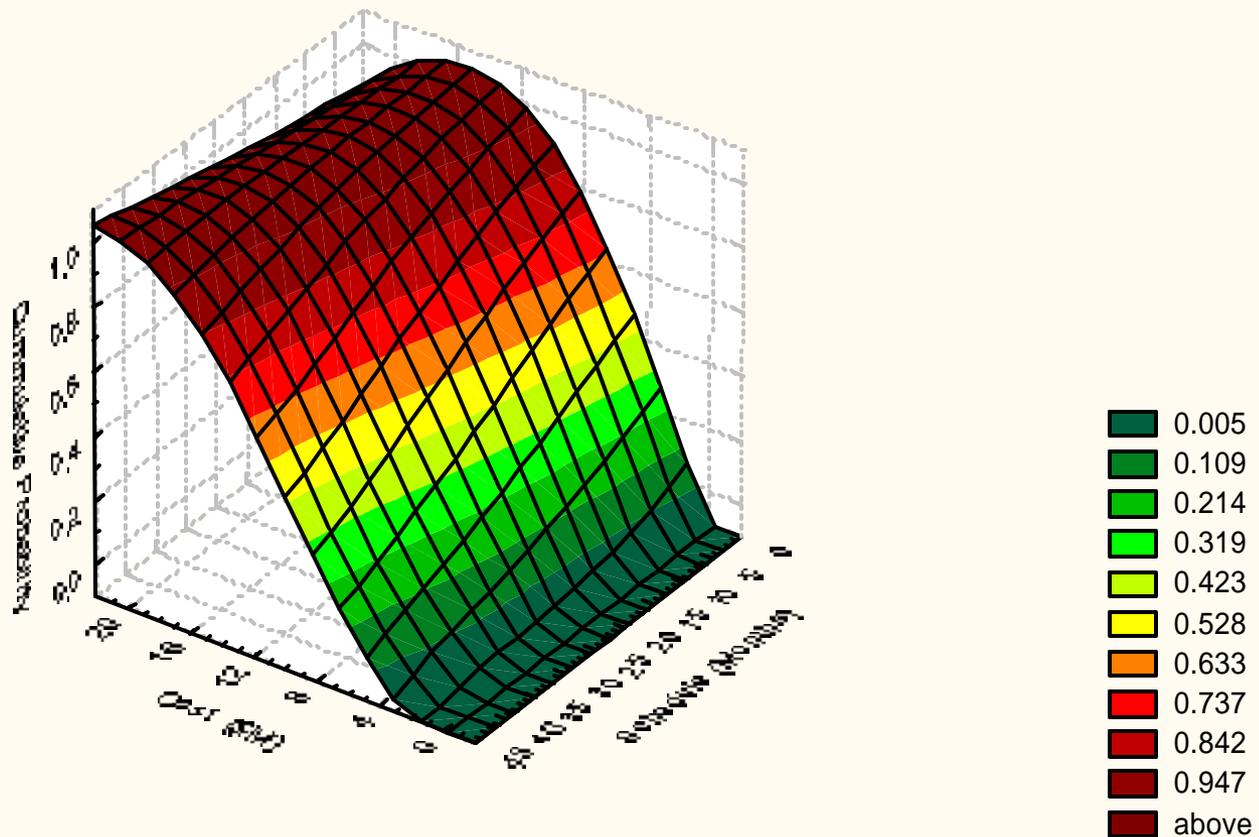
Joint Probability Density Function (PDF)

Probability Density Function, Cost Conditioned to Schedule



Joint Cumulative Distribution Function (CDF)

Cummulative Distribution Function, Cost Conditioned to Schedule





Conditional Probability Variables

<u>Term</u>	<u>Variable</u>
Mean of Cost Distribution	μ_{X1}
Mean of Schedule Distribution	μ_{X2}
Variance of Cost Distribution	$(s_{X1})^2$
Variance of Schedule Distribution	$(s_{X2})^2$
Correlation of Cost and Schedule	$\rho_{X1,X2}$

Joint Distributions are too difficult to explain to decision makers!

Conditional Probability Equations

- The conditional expectation (mean) of program cost (X_1) given a schedule duration (x_2):

$$E(X_1 | x_2) = x_2 \frac{s_1}{s_2} r_{1,2} e^{m_1 - \frac{s_1}{s_2} r_{1,2} m_2 + \frac{1}{2} s_1^2 (1 - r_{1,2}^2)}$$

- The conditional variance of program cost (X_1) given a schedule duration (x_2):

$$Var(X_1 | x_2) = x_2^2 \frac{s_1}{s_2} e^{2(m_1 - \frac{s_1}{s_2} r_{1,2} m_2)} e^{z^*} (e^{z^*} - 1)$$

where,

$$r_{1,2} = \frac{1}{s_1 s_2} \ln \left[1 + r_{x_1, x_2} \sqrt{e^{s_1^2} - 1} \sqrt{e^{s_2^2} - 1} \right]$$

and,

$$Z^* = s_1^2 (1 - r_{1,2}^2)$$



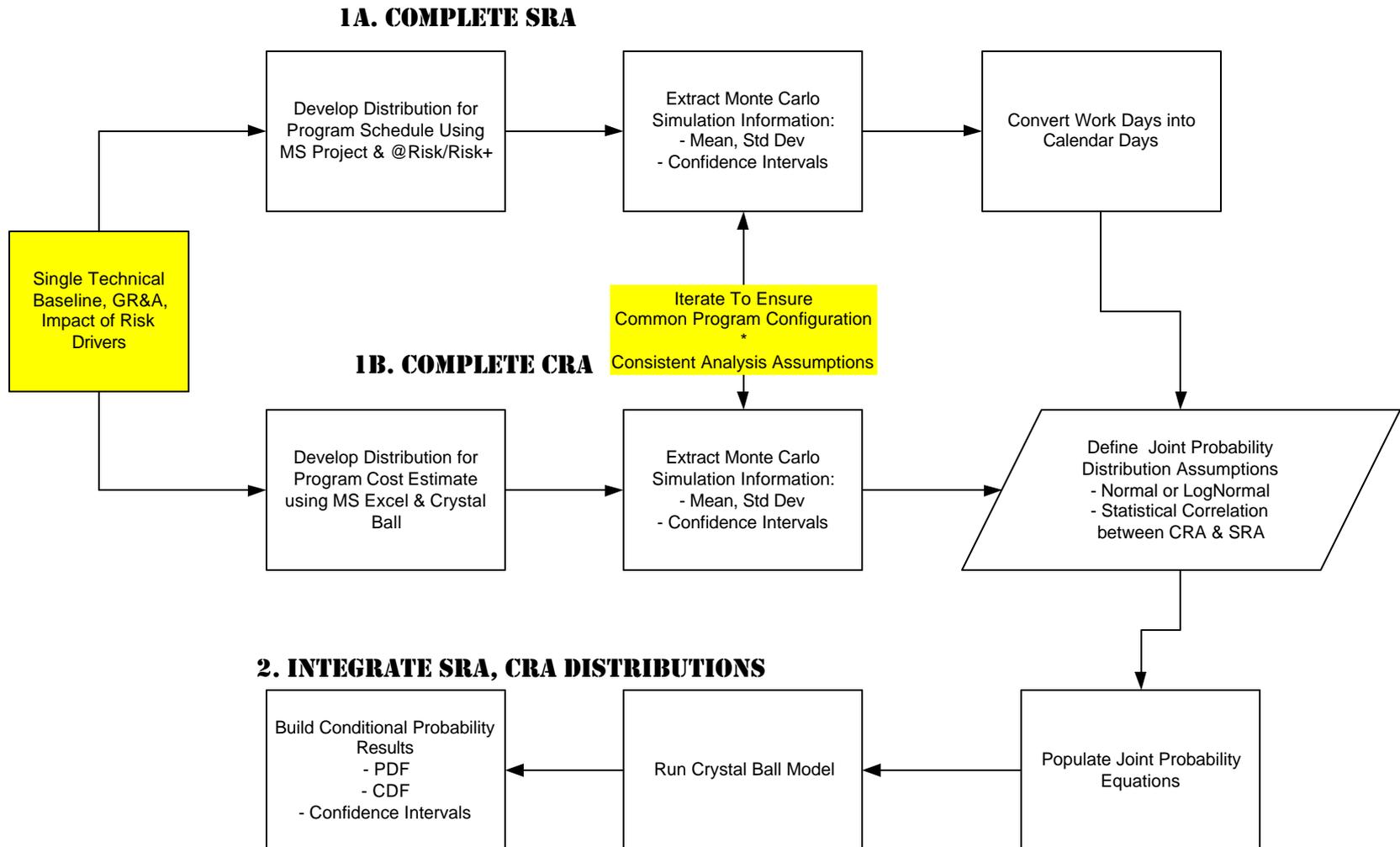
Recommended Solution

Two-step, top-down approach

1. Depend on current cost risk analysis (CRA) and schedule risk analysis (SRA) to generate program/alternative-level cost and schedule probability distributions
 - CRA, SRA conducted independently, using appropriate tools and processes:
 - CRA: MS Excel™ with Crystal Ball/@Risk or ACE-IT RI\$K
 - SRA: MS Project™ with Risk+/@Risk
 - CRA, SRA must be based on same technical baseline
2. Integrate the program/alternative-level cost and schedule distributions mathematically
 - Apply Bivariate Distribution Theory demonstrated initially by P.R. Garvey, MITRE, in 1996 and now applied to DoD, Civilian and Intelligence programs
 - Implemented using MS Excel and Crystal Ball™



Recommended Solution: Analysis Process





Recommended Solution: Data Requirements

- Cost Risk Analysis (CRA) probability distribution, including...
 - Mean and Standard Deviation of program-level distribution, in dollars
 - Confidence level of specified budget value
 - Cost forecasts for specified confidence intervals (e.g., 50%, 80%)
- Schedule Risk Analysis (SRA) probability distribution, including,
 - Mean and Standard Deviation of program-level distribution, in calendar days
 - Confidence level of specified end date for cost estimate (e.g., FOC date or end of production)
 - Calendar duration forecasts for specified confidence intervals (e.g., 50%, 80%)



Recommended Solution: Key Assumptions

- Distribution shapes: lognormal or normal
 - Can be determined by skewness observed in independent Monte Carlo simulations for program level cost and schedule
 - As a rule, simulation based on large numbers of WBS elements yields a normal distribution – otherwise lognormal works
- Correlation between CRA and SRA distributions
 - Many risk drivers are common to both the CRA and SRA
 - Correlation coefficients represent the magnitude of common risk impact that is resident both in CRA or SRA that should have been modeled discretely but was omitted
 - Does not reproduce or replace the correlation between elements within either the cost WBS or the schedule activity network

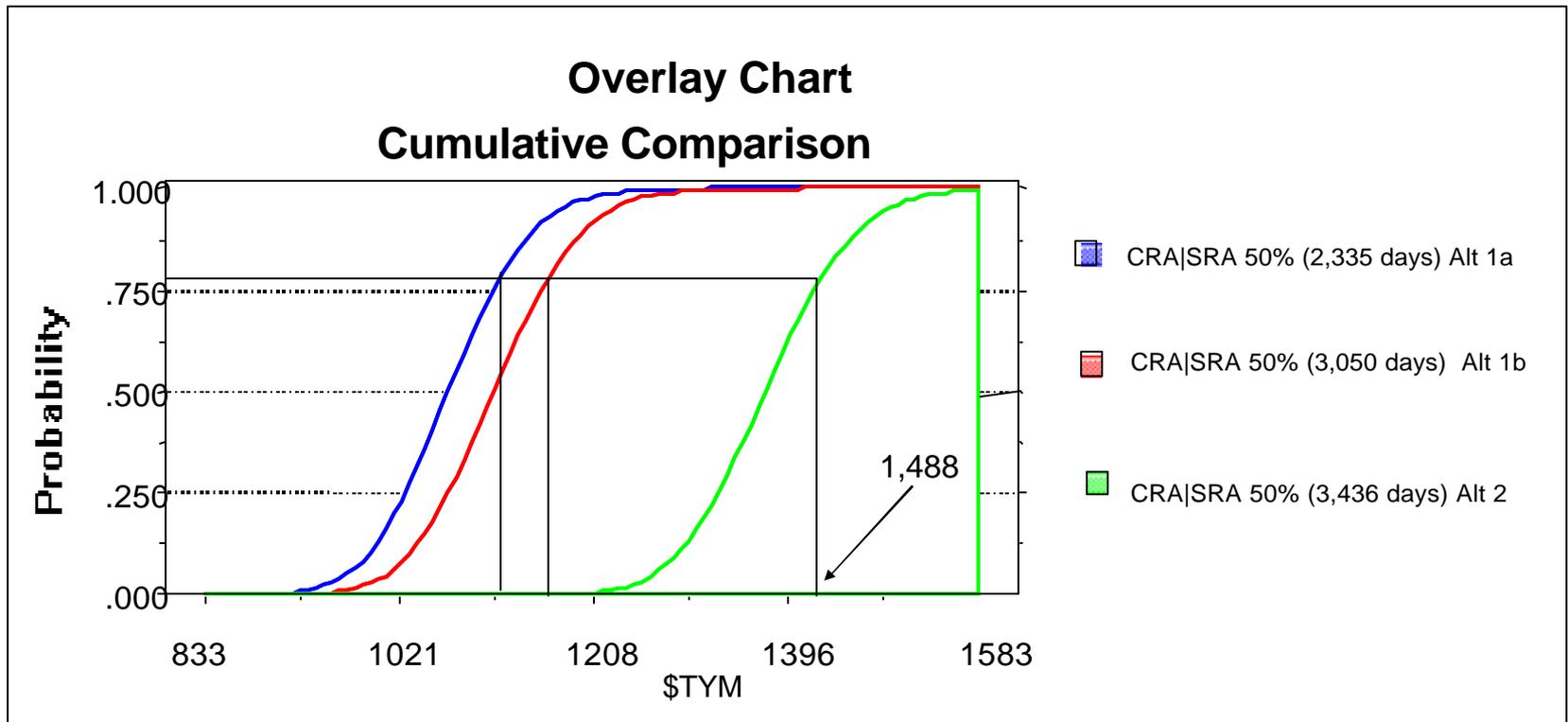


Sample Analysis Results

- Based on data from recently completed program
- Three alternatives (1a, 1b, 2)
- CRA, SRA probability distributions available for each of the alternatives
- Correlation between CRA, SRA assumed to be 0.50
- All dollars presented in Then Year (TY)
- All days presented in Calendar Days
- Graphic & tabular results follow....

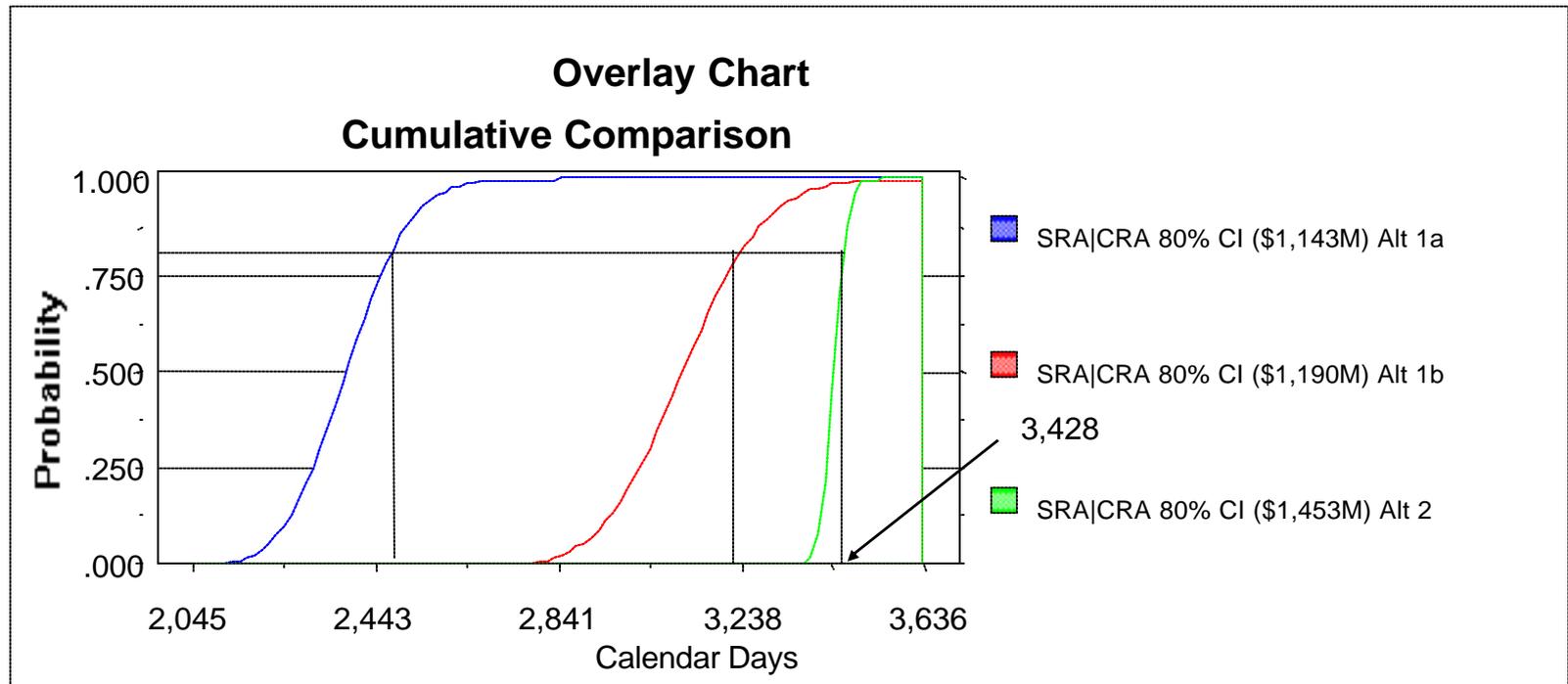


Sample Results: Setting 50% Schedule Confidence Level as a Constant for all Cost Alternatives



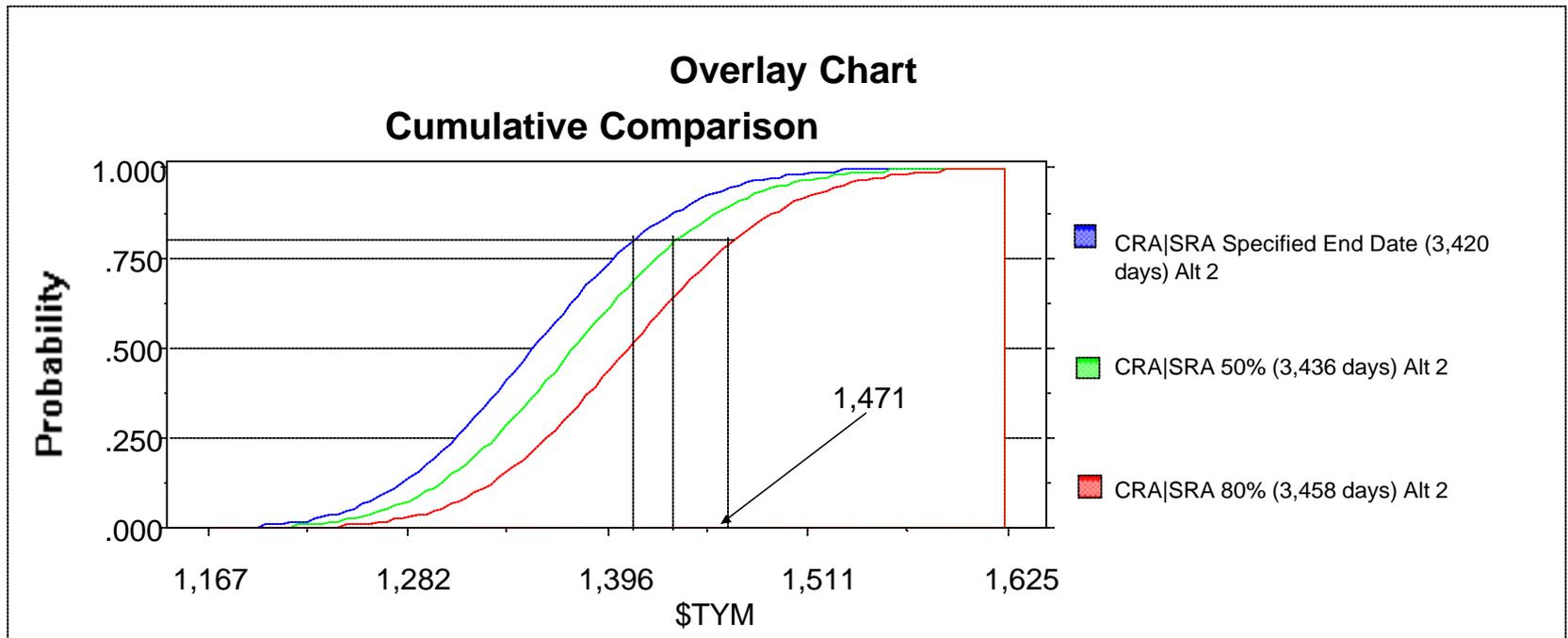


Sample Results: Setting 80% Cost Confidence Level as a Constant for all Schedule Alternatives





Sample Results: Setting Schedule Date as a Constant for a Cost Alternative (Alt 2)



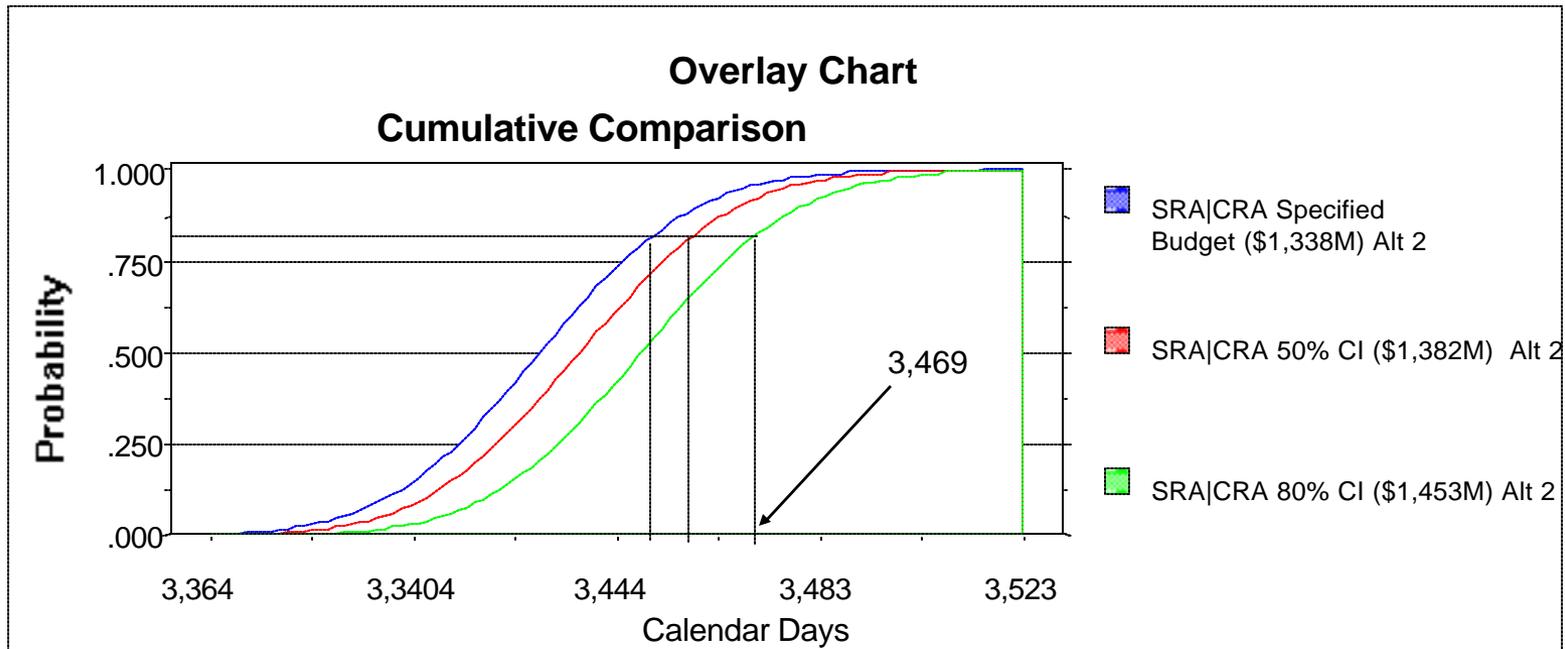


Sample Numerics: Setting Schedule Date as a Constant for a Cost Alternative (Alt 2)

	SRA Specified Budget (3420 Days) \$M	SRA 50% (3436 Days) \$M	SRA 80% (3458 Days) \$M
1%	1124	1132	1163
10%	1272	1294	1323
20%	1300	1323	1353
30%	1321	1344	1374
40%	1339	1362	1393
50%	1356	1379	1411
60%	1373	1397	1428
70%	1392	1416	1448
80%	1414	1438	1471
90%	1445	1470	1504
99%	1634	1688	1704



Sample Results: Setting Dollar Value of Cost as a Constant for a Schedule Alternative (Alt 2)





Sample Numerics: Setting Dollar Value of Cost as a Constant for a Schedule Alternative (Alt 2)

SRA CI	CRA Specified Budget (\$1338M)	CRA 50% (\$1382M)	CRA 80% (\$1453M)
Percentile	Days	Days	Days
1%	3,345	3,345	3,363
10%	3,398	3,406	3,418
20%	3,409	3,416	3,428
30%	3,416	3,424	3,436
40%	3,423	3,431	3,442
50%	3,429	3,437	3,449
60%	3,435	3,443	3,455
70%	3,441	3,449	3,461
80%	3,449	3,457	3,469
90%	3,460	3,468	3,480
99%	3,516	3,527	3,555



Path Forward to Standard Operating Procedure

- Establish a formal Schedule Risk Analysis process to generate probability distribution
 - Define duration distributions in networked schedules
 - Typically networked schedule is either not developed or not available to the government program office
- Prepare rule set for establishing critical assumptions
 - Program-level distribution type: Normal vs LogNormal
 - Correlation coefficient
- Develop draft documentation templates
 - Explanation of method & interpretation guides
 - Microsoft PowerPoint and Word formats



Typical Changes to Existing Processes

- Two major changes:
 - Ensure that CRA and SRA are based on common technical baseline
 - Same program configuration—confirmation especially important if technical baseline evolved during Investment Analysis process
 - Consistent set of ground rules and assumptions
 - Access to same risk mitigation data and recommendations
 - Convert SRA data into calendar days
 - Currently portrayed as business days
 - Conversion using MS Project schedule preferred over ratio conversion
 - Explicitly compare CRA and SRA
 - Common program configurations (technical baselines)
 - Consistent analysis assumptions
- Changes require modest additional effort per program/alternative
 - Populate and execute the model
 - Diagnose and correct for inconsistencies
 - Develop decision aids



Advantages of Recommended Solution

- Exploits data already being generated
- Minimizes requirements for additional data
- Does not require product teams to generate program/alternative details that are not already available
- Methodology simple to implement, using Excel & Crystal Ball
- Methodology relatively easy to understand
- Results apply to the program level
- Enables comparison between alternatives, within alternatives (for cost and schedule pairings)
- Increases credibility of cost and schedule estimates

Does not support budget/duration trade-offs
This is accomplished with bottom-up approach



Expected Benefits

- Improved ability to explain joint cost and schedule impacts at total program level
 - Model impact of holding schedule (or cost) constant on resource forecasts
 - Ensure tracability of risk drivers to independent risk analyses
 - Contribution of variance for CRA
 - Criticality index for SRA
 - Compare Investment Analysis alternatives at consistent confidence levels for cost and schedule risk
- Provides a crosscheck of the CRA and SRA
 - Ensures that analyses are based on a common technical baseline and set of ground rules & assumptions
 - Compare Investment Analysis alternatives at consistent confidence levels for cost and schedule risk



Expected Benefits (cont)

- Improved resource allocations
 - Budget forecasts are understated if cost impact of schedule risk is omitted
 - Planned schedule durations are unknowingly optimistic if schedule impact of cost risk is omitted
- Program-level impact of setting a constant
 - Confidence level-budget forecast given a target schedule date
 - Confidence level-program duration forecast given a target budget value

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Backup



Alternate Solution: “Bottom Up” Approach

- Cost estimates and program schedule complementary structured at a low level
 - Activities and WBS elements are mapped
 - Estimates of resources (labor and material) are reflected in the schedule
 - Activity durations and logic links are reflected in estimates
- Cost and schedule risk ranges dependencies are defined explicitly in each model
 - Trade-offs at WBS element/Activity level are possible
 - Program level distributions achieved through Monte Carlo Simulation