NPS-AM-10-069

EXCERPT FROM THE PROCEEDINGS

OF THE

SEVENTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM THURSDAY SESSIONS VOLUME II

Acquisition Research
Creating Synergy for Informed Change

May 12 - 13, 2010

Published: 30 April 2010

Prepared for: Naval Postgraduate School, Monterey, California 93943

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **MAY 2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE **PEO-IWS ACB Insertion Portfolio Optimization**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Monterey,CA,93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
7th Annual Acquisition Research Symposium to be held May 12-13, 2010 in Monterey, California

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**53**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The research presented at the symposium was supported by the Acquisition Chair of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

To request Defense Acquisition Research or to become a research sponsor, please contact:

NPS Acquisition Research Program
Attn: James B. Greene, RADM, USN, (Ret.)
Acquisition Chair
Graduate School of Business and Public Policy
Naval Postgraduate School
555 Dyer Road, Room 332
Monterey, CA 93943-5103
Tel: (831) 656-2092
Fax: (831) 656-2253
E-mail: jbgreene@nps.edu

Copies of the Acquisition Sponsored Research Reports may be printed from our website www.acquisitionresearch.net

PEO-IWS ACB Insertion Portfolio Optimization[1]

Johnathan Mun, Tom Housel and Mark D. Wessman

Overview

Program Executive Office–Integrated Warfare Systems (PEO-IWS) engaged a team from the Naval Postgraduate School (NPS) to conduct a pilot study to apply the Knowledge Valued Added + Real Options + Integrated Risk Management + Portfolio Optimization (KVA + RO + IRM + PO) method to estimate the value stream created by the capabilities to be inserted within the Aegis Weapons System (AWS) through the Advanced Capability Build (ACB) process—as described in the PEO-IWS Surface Combat System Acquisition Management Plan (AMP)—given budget constraints and ship industrial availability schedules. The goal was to determine what order of capability insertion provided the best returns within an optimized portfolio, treating each capability as a real option. The KVA + RO + IRM + PO approach was used to estimate the warfighter value delivered by each capability within the context of a portfolio-optimization, integrated risk-management model. The results provide a set of options based on selected constraints for insertion of the capabilities over the period of interest (Fiscal Years 2014–2025) based on an optimized portfolio model. For detailed information on the KVA + RO +IRM + PO approach, see the technical appendix to this report.

The pilot study analysis articulated a notional value measure of military capability for a specified set of 23 capabilities to be considered, and examined four discrete approaches: (1) a ranking by value within a constrained total integration budget (optimal on budget), (2) a similar ranking by value and budget with a risk constraint added (optimal cost-risk), (3) ranking by value constrained by integration budget, with the additional constraint that a particular capability must be included in the first increment (Capability 2 must-have), and (4) the portfolio with the specified capability in the first increment and a risk constraint added (Capability 2 cost-risk). Each approach generated a distinct recommendation for the composition and sequencing of the capabilities within the ACB schedule. Under the ACB model, capabilities will be inserted within the AWS system every two years. ACBs are identified by the fiscal year in which the first ship receives the software upgrade. The analysis encompassed ACB 14 (2014) through ACB 18 (2018). The analysis included all the ships that would receive the ACBs for each two-year period from 2014–2025, and accounted for the ships being phased into the program through scheduled repair availability periods. This period was selected because at the end of that time, all ships with the AWS would have been inducted into the process. The analysis assumes that value would begin to accrue for a given ship as soon as an ACB was implemented in that ship and would continue to accrue through subsequent ACBs throughout the service life of the ship. ACBs beyond ACB 18 were not considered for the pilot analysis, but both additional capabilities and future ACBs can easily be added to the analysis. Within the ACB process, a ship

[1] The analyses performed (Monte Carlo risk simulation, dynamic optimization, and real options analysis) apply the Risk Simulator software and ROV Modeler software tools available from Real Options Valuation, Inc. (www.realoptionsvaluation.com), and the software screen shots were reprinted with their permission. Although there exist several commercial off-the-shelf software products available for running optimization, Risk Simulator and ROV Modeler were the only tools found to be suitable due to their ability in handling real options analysis, stochastic optimization, risk simulation, and other requirements in the analyses performed. These software tools were developed by the author, Dr. Johnathan Mun.

receives the current ACB, as well as the previous ACBs not yet completed. For example, a ship entering the program with ACB 18 also receives the capabilities from ACB 14 and ACB 16 at the same time. A ship that receives the first ACB as ACB 14 will receive its next update with ACB 18 but will receive the ACB 16 capabilities at the same time. Aggregation of the value for individual ships provides a measure in terms of capability-ship-years.

Within the context of the KVA approach, the study assumed that a relatively objective and extensible metric for military value was the relative complexity of the software modules that implement each capability in the open architected AWS, and that the complexity of the component could be represented by the relative magnitude of the number of delivered source lines of code (DSLOC), given that the programming languages used were comparable. A second measure of relative military value was achieved through collection of subject-matter expert (SME) rankings of relative component complexity and mission criticality. The study methodology aggregated the component data to the capability level using SME mapping of components to capabilities. These measures correlated highly with the DSLOC rankings, providing a validation of the assumption that relative magnitude of DSLOC can provide a measure of military value. SME estimates of the complexity of code and DSLOC were presumed to be those of the capability components themselves (versus simply the integration) since warfighting functionality (the military value of the system) was implemented by the component. Integrating the components/capabilities into the system made the warfighting functions of the components/capabilities available to the user.

The cost basis for each insertion employed for the study was based on an aggregated average of high-, medium-, and low-cost estimates to integrate the required components into the AWS for given capability insertions. Cost of integration was used as the key cost parameter to provide the analysis based on PEO-IWS 1's perspective as the integrating agent, versus as a component provider. The correlations among the subjective measure of military value and relative complexity of components derived from judgments of SMEs from PEO-IWS 1.0 and the Naval Surface Warfare Center Dahlgren Division (NSWCDD) were very high, indicating that the estimates were reliable (Table 1). The correlation between costs for the insertions and value described using this method was very low, indicating that integration cost does not predict military value. These findings support the need for using the KVA method to determine expected military value (EMV), the objective measure used in portfolio optimization and selection.

The toolset applied—using real options, portfolio optimization, and integrated risk management—provides a means for quickly estimating the effects of various capability insertions over the period of interest. It provides management with the flexibility to examine various ACB capability insertion options given budget and ship availability constraints. The analysis for this study employed the following steps:

1. Data collection and analysis to determine the best proxy for Expected Military Value (EMV), using objective data on DSLOC, subject-matter estimates of complexity and mission criticality for each capability, and OPNAV (Chief of Naval Operations staff) sponsor and technical community priorities for each capability.
2. Static and dynamic optimization runs based on four different EMV measures for multi-criteria optimization, to determine the best allocation and selection of capabilities given a nominal $150 million budget constraint for each ACB, using a range of cost estimates for integration provided by SMEs.

3. Combination of the four EMV methods to obtain the portfolio of options, results and recommendations for sequencing capability insertions for ACB 14, ACB 16, and ACB 18.
4. Computation of aggregate EMV values through the insertions of ACBs using actual planned ship-availability schedules as published in the Surface Ship Acquisition Management Plan (AMP).
5. Monte Carlo risk simulation of cost estimates to determine risk of budget and cost overruns.
6. Generation of an alternate scenario by applying OPNAV's Priority 1 capability (Capability 2) as a "must-have" in the portfolio selection, and identification of what other capabilities should be inserted in such a scenario and how this would affect accrued value over the ACB insertion timeframe.
7. Determination of a Portfolio Efficient Frontier, in which we determine multiple scenarios of increasing budget (i.e., if the $150 million budget were increased to $200 million, or $250 million, or $300 million, etc., what will the optimal portfolio look like for each budget; what capabilities should be added or replaced, and what would be their impacts on EMV?).
8. Repetition of the previous analyses—with an additional constraint that the portfolio selected must have an 85% or greater probability of completing within budget.

As follow-on to the work documented in this report, PEO-IWS should consider the following:

1. Strategic Real Options or analysis of alternatives, examining various courses of action should certain capabilities be linked or nested with respect to another (e.g., there might be a "platform capability" that might have a high initial cost but bring significant downstream options for add-on capabilities with significant EMV. Or, there may be mutually exclusive or dependent capabilities—with which the implementation of capability precludes another from being implemented or requires another to be implemented, or will reduce the cost and increase the total EMV of another capability when they are implemented together).
2. Additional modeling, such as adding new capabilities to the list, adding considerations of additional risk factors (e.g., technical, schedule).
3. Training and software implementation for risk simulation and optimization.

Adoption of the foregoing will lead to a more refined and robust analysis of the value, risk, and cost of future options for capability insertions for the Aegis system. The remainder of the report is sequenced as follows:

- Statement of Work (SOW) Objectives
- Problem Formulation
- Methodology

Table 1. Data Collection

Table 2. Portfolio Optimization

Table 3. Expected Military Value

Table 4. Sequencing of ACB 14, ACB 16, ACB 18

Table 5. Alternate Scenario: Capability 2 Must-Have

Table 6. Aggregate EMV

Table 7. Monte Carlo Risk Simulation

Table 8. Portfolio Optimization’s Efficient Frontier

Table 9. Optimization with a Risk Constraint

Statement of Work Objectives

The focus of this work is to conduct a pilot study to provide return on investment and real options/portfolio optimization analysis to help articulate value proposition in selection of capabilities for inclusion in the modernization of the Aegis Weapons System (AWS) in US Navy cruisers and destroyers. The analysis was to be demonstrated in a manner that would support the next budget submission cycle. In addition, the project was to use the Knowledge Value Added + Real Options + Integrated Risk Management + Portfolio Optimization (KVA + RO + IRM + PO) methodology, with supporting software, to aid in the process performance analysis and option-value estimation. The customer selected the processes and systems for the analysis to establish the baseline return on investment (ROI) estimates. This project focused on conducting the KVA + RO + IRM + PO analysis on the identified ACB insertion options by working with PEO-IWS 1 and NSWCDD personnel to establish the necessary baselines and analyses and, concurrently, to lay the foundation for developing the level of knowledge necessary for the organization to use and maintain the toolset going forward. This approach ensures that the managers of the process have a decision toolset and the knowledge to interpret the results of the analysis outputs. These tools include the applications of risk analysis, forecasting, risk hedging and management strategies, strategic real-options applications, project portfolio optimization and selection, and other related analytics. In addition, aggregate numbers used to support the building of a business case to meet the acquisition community requirements for the selected problem space were also to be documented. Management-level reports were provided to evaluate ongoing OA acquisition initiatives. The products of the pilot were developed in a manner that can provide a basis for extension and implementation across the PEO as a method and toolset to be used on an ongoing basis. This extended use will provide the ability to better manage acquisition decisions and to make the case for those decisions to both sponsors and the Acquisition chain of command.

Problem Formulation

The US Navy is constantly faced with many difficult portfolio optimization decisions. These decisions include allocating financial resources, building or expanding facilities and capabilities, and determining acquisition strategies. Such decisions might involve thousands or millions of potential alternatives. Considering and evaluating each of them would be impractical or even impossible. A model can provide valuable assistance in incorporating relevant variables when analyzing decisions and finding the best solutions for making decisions. Models capture the most important features of a problem and present them in a form that is easy to interpret. Models often provide insights that intuition alone cannot. An optimization model has three major elements: *decision variables, constraints,* and *objectives*. The optimization methodology finds the best combination or permutation of decision variables (e.g., which strategies to pursue and which projects to execute) in every conceivable way such that the objective is maximized (e.g., return on investment, military value-added, proxies for revenues and income) or minimized (e.g., risk and costs) while still satisfying the constraints (e.g., budget and resources).

In order to obtain optimal values, one generally must search in an iterative or ad hoc fashion. This search involves running one iteration for an initial set of values, analyzing the results, changing one or more values, rerunning the model, and repeating the process until finding a satisfactory solution. This process can be very tedious and time-consuming, even for small models, and often it is not clear how to adjust the values from one iteration to the next. A more rigorous method systematically enumerates all possible alternatives. This approach guarantees optimal solutions if the model is correctly specified. If an optimization model depends on only two decision variables, and if each variable has 10 possible values, then trying each combination requires 100 iterations (10^2 alternatives). If each iteration is very short (e.g., two seconds), then the entire process could be done in approximately three minutes of computer time. However, instead of two decision variables, if the option set includes "go" or "no-go" decisions on 23 alternative selections—as in the case of the current ACB analysis—then trying all combinations requires 2.58×10^{22} iterations of alternatives. It is easily possible for complete enumeration to take months or even years to carry out on a supercomputer. Practicality, then, demands that the analyst employ some advanced algorithms and techniques in Risk Simulator and ROV Modeler for running the portfolio selection and optimization. Before embarking on solving an optimization problem, it is vital to understand the terminology of optimization—the terms used to describe certain attributes of the optimization process. These words include *decision variables*, *constraints*, and *objectives*.

Decision Variables are quantities over which the decision-makers have control; for example, the amount of a product to make, the number of dollars to allocate among different investments, or which projects to select from among a limited set. As an example, portfolio optimization analysis includes a "go" or "no-go" decision on particular projects. In addition, the dollar or percentage budget allocation across multiple projects also can be structured as decision variables.

Constraints describe relationships among decision variables that restrict the values of the decision variables. For example, a constraint might ensure that the total amount of money allocated among various investments cannot exceed a specified amount or, at most, one project from a certain group can be selected. Constraints also include budget and timing restrictions, minimum returns, or risk-tolerance levels.

Objectives give a mathematical representation of the model's desired outcome—such as maximizing EMV, benefits, and profit, or minimizing cost and risk—in terms of the decision variables. In financial analysis, for example, the objective may be to maximize returns while minimizing risks (maximizing the Sharpe's ratio or returns-to-risk ratio).

The solution to an optimization model provides a set of values for the decision variables that optimizes (maximizes or minimizes) the associated objective. If the real business conditions were simple, and if the future were predictable, then all data in an optimization model would be constant, making the model deterministic. In many cases, however, a deterministic optimization model cannot capture all the relevant intricacies of a practical decision-making environment. When a model's data are uncertain and can only be described probabilistically, the objective will have some probability distribution for any chosen set of decision variables. The analyst can find this probability distribution by simulating the model using Risk Simulator. An optimization model under uncertainty has several additional elements, including assumptions and forecasts.

Assumptions capture the uncertainty of model data using probability distributions, whereas forecasts are the frequency distributions of possible results for the model. Forecast statistics are summary values of a forecast distribution, such as the mean, standard deviation, and variance. The optimization process controls the optimization by maximizing or minimizing the objective. Each optimization model has one objective, a variable that mathematically represents the model's objective in terms of the assumption and decision variables. Optimization's job is to find the optimal (minimum or maximum) value of the objective by selecting and improving different values for the decision variables. When model data are uncertain and can only be described using probability distributions, the objective itself will have some probability distribution for any set of decision variables. In the current project's optimization analysis, the problem formulation is to optimize the Aegis ACB composition based on:

- Potential return on capability (return on investment, expected military value, and other multiple criteria),
- Investment constraints (e.g., $150 million per ACB cycle),
- Ship schedule and availability, and
- Selecting the best combinations and permutations of capabilities using the portfolio optimization approach as a series of options.

Methodology

In this section, we discuss the methodology employed in more detail, with particular emphasis on the high-level understanding of the approach and the results. For the technical mathematical constructs, please refer to the Appendix for additional technical background readings. Briefly, the methodology employed is divided into several steps, as covered in the following subsections.

Data Collection

Data collection and analysis is the first step employed to determine the best proxy for Expected Military Value (EMV) and cost estimates of each capability. To that end, we relied on data ranging from objective values such as delivered source lines of code (DSLOC) of software, semi-objective measures such as estimates of integration cost for each capability (using high, most-likely, and low estimates for cost, so that we can perform a Monte Carlo risk simulation later), to more subjective estimates from subject-matter experts (SMEs) on the amount of functional complexity and operational criticality for each component. PEO-IWS representatives also provided OPNAV and acquisition community priorities for each capability. The analysis demonstrated that complexity is proportionate to value, but there were low correlations between EMV and cost estimates—indicating that we cannot reliably use cost alone as an estimate to determine the best portfolio allocation for maximizing EMV. The correlation matrix is shown in Table1.

Table 1. Correlation Matrix

Linear Correlation Matrix	*Cost Midpoint*	*SME Mean Value Added*	*DSLOC Complexity*	*Technical Priority H-L*	*OPNAV Priority H-L*	*EMV: SMEVA and DSLOC*	*EMV: All Weighted & Common Sized*	*EMV: OPNAV & Technical*	*EMV: OPNAV & DSLOC*
Cost Midpoint	1								
SME Mean Value Added	0.07	1							
DSLOC Complexity	0.40	0.84	1						
Technical Priority H-L	0.46	0.42	0.42	1					
OPNAV Priority H-L	0.34	0.49	0.43	0.89	1				
EMV: SMEVA and DSLOC	0.39	0.86	1.00	0.42	0.44	1			
EMV: All, Weight, Sized	0.36	0.91	0.93	0.65	0.69	0.94	1		
EMV: OPNAV & Technical	0.41	0.47	0.44	0.97	0.97	0.44	0.69	1	
EMV: OPNAV & DSLOC	0.44	0.82	0.90	0.72	0.78	0.90	0.98	0.77	1

Risk and uncertainty can also be estimated based on various criteria (in the current analysis, we use cost uncertainty as a proxy for risk), and value is assumed to be generated as capabilities are realized through installation in specific ships over time. To get started with the data collection, we had to perform the following steps:

- Establish operational definitions of value and cost of each ACB capability insertion.
- Identify the projected ship schedule to establish availability for ACB insertions every two years.
- Obtain SME identification and description of ACB components and capabilities.
- Undertake model generation and iterations with various inputs, including running cross-correlations to determine the impact and validity of SME estimates.

The data sources used include:

- AMP Ver. 5.4 (27 Oct 2008) documentation of moving to an OA approach in ACB insertions,
- Ship schedule, capability candidates for integration, components of the system to be changed (mapped to the capabilities), and integration cost for each capability provided by IWS 1,
- SMEs estimates of complexity and mission criticality for components, and
- DSLOC for each component.

Figure 1 shows a sample of the collected data used in the analysis. The analysis began by assuming 23 capabilities (more can be added later as required). Next, the analysis applied the average of the SME value-added estimates; the high, most-likely, and low cost estimates; the OPNAV and technical priorities; and the DSLOC for each component, as specified in the *Surface Combat System Objective Architecture*. Using these raw variables, we generated various EMV metrics by accounting for the SME mean value-added estimates and DSLOC, and weighting them—as well as common-sizing their mean values—to determine a comprehensive metric, considering OPNAV and technical priority only, and combining OPNAV priority with DSLOC estimates. Clearly, other metrics can be easily applied in the model if required.

Multicriteria Objectives

Common sizing inputs and using weights to obtain EMV

	Common Size Factor			1.00			0.10		2.00	2.00			OPNAV Weight	50%		
	Weighting Scheme			35%			35%		15%	15%	SMEVA and DSLOC Only	All Weighted & Common Sized	OPNAV & Technical Priority	OPNAV Priority & DSLOC		
Capability	High	Mid	Low	SME Mean Value Added	Technical Priority	OPNAV Priority	DSLOC Complexity	Cost Simulation	Technical Priority H-L	OPNAV Priority H-L	EMV Score	EMV Score	EMV Score	EMV Score	Objective Used	CV
Capability 1				43.00	3	2	278		21	22	321.00	37.68	43.00	35.90	37.68	0.1834
Capability 2				28.00	2	1	541		22	23	569.00	42.24	45.00	50.05	42.24	0.0903
Capability 3				13.00	1	3	58		23	21	71.00	19.78	44.00	23.90	19.78	0.0719
Capability 4				40.33	5	4	635		19	20	675.33	48.04	39.00	51.75	48.04	0.0576
Capability 5				17.67	7	7	134		17	17	151.67	21.07	34.00	23.70	21.07	0.0407
Capability 6				35.67	4	6	392		20	18	427.67	37.60	38.00	37.60	37.60	0.1568
Capability 7				50.67	6	5	549		18	19	599.67	48.05	37.00	46.45	48.05	0.0481
Capability 8				47.67	10	11	675	Data Redacted	14	13	722.67	48.41	27.00	46.75	48.41	0.0689
Capability 9		Data Redacted		19.00	8	8	109		16	16	128.00	20.07	32.00	21.45	20.07	0.0382
Capability 10				33.67	11	9	189		13	15	222.67	26.80	28.00	24.45	26.80	0.0603
Capability 11				20.00	9	10	88		15	14	108.00	18.78	29.00	18.40	18.78	0.0707
Capability 12				27.67	14	12	159		10	12	186.67	21.85	22.00	19.95	21.85	0.1137
Capability 13				27.67	12	13	159		12	11	186.67	22.15	23.00	18.95	22.15	0.0408
Capability 14				44.67	13	14	523		11	10	567.67	40.24	21.00	36.15	40.24	0.0956
Capability 15				17.67	20	15	134		4	9	151.67	14.77	13.00	15.70	14.77	0.0603
Capability 16				17.67	21	16	134		3	8	151.67	14.17	11.00	14.70	14.17	0.0816
Capability 17				34.33	19	17	328		5	7	362.33	27.10	12.00	23.40	27.10	0.0454
Capability 18				17.67	22	18	134		2	6	151.67	13.27	8.00	12.70	13.27	0.0372
Capability 19				14.00	23	19	81		1	5	95.00	9.54	6.00	9.05	9.54	0.0340
Capability 20				17.67	15	20	134		9	4	151.67	14.77	13.00	10.70	14.77	0.0164
Capability 21				22.67	18	21	144		6	3	166.67	15.67	9.00	10.20	15.67	0.0454
Capability 22				11.67	16	22	180		8	2	191.67	13.38	10.00	11.00	13.38	0.0468
Capability 23				10.00	17	23	95		7	1	105.00	9.23	8.00	5.75	9.23	0.0603

Starting with 23 capabilities, more to be added later

High, likely, low values for running risk simulations

Technical and OPNAV priorities

Complexity modeled using DSLOC

Intermediate computations: risk simulation assumptions, re-adjusted priorities, expected military score, cost -based risk coefficients

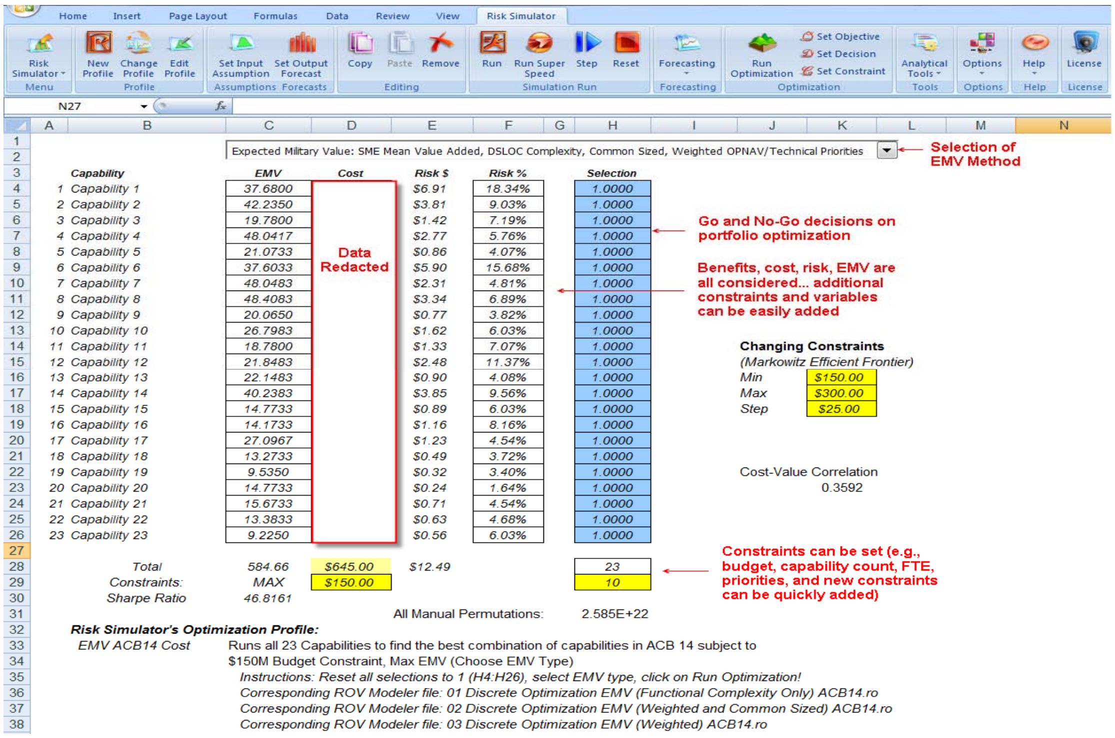
Input Assumptions

Portfolio Optimization

Static and dynamic optimization runs were executed based on four different EMV measures for multi-criteria optimization to determine the best allocation and selection of capabilities given a nominal $150 million budget constraint for each ACB. Figure 2 shows the portfolio optimization model, in which we have the 23 capabilities listed (clearly, we can add as many additional capabilities as required, as long as we have valid data and assumptions for each capability). The EMV values (column C in Figure 2) show the value of the composite EMV metric, depending on the calculation method chosen, the EMV value using risk-simulated cost estimates (column D), and EMV value using an estimate of risk (columns E and F) for each component (for the initial study, we impute the risk as the budget cost overrun and variability, whereas we can add additional variables and measures of risk later, as required). Finally, there is a column of decision variables, or “go” and “no-go” variables (column H), which are the decisions that are being optimized, such that the total portfolio EMV objective (cell C28) is maximized. The total cost of the portfolio is also computed (cell D28), and the portfolio is run subject to a cost constraint of less than or equal to $150 million (cell D29). For future applications, we can add to the existing optimization model by also considering:

- Additional Capabilities as required, beyond the initial list of 23,
- Optimization and selection of Components, instead of Capabilities,
- New and alternate EMV metrics beyond the four EMV estimates currently used,
- Additions of cross-constraints such as mutually exclusive projects and capabilities, and the dependence of one capability on another,

- Inclusion of additional constraints such as full-time equivalences, facilities, etc., and
- Estimates of technical or schedule risk.



Expected Military Value: SME Mean Value Added, DSLOC Complexity, Common Sized, Weighted OPNAV/Technical Priorities

Selection of EMV Method

	Capability	EMV	Cost	Risk $	Risk %	Selection
1	Capability 1	37.6800	Data Redacted	$6.91	18.34%	1.0000
2	Capability 2	42.2350		$3.81	9.03%	1.0000
3	Capability 3	19.7800		$1.42	7.19%	1.0000
4	Capability 4	48.0417		$2.77	5.76%	1.0000
5	Capability 5	21.0733		$0.86	4.07%	1.0000
6	Capability 6	37.6033		$5.90	15.68%	1.0000
7	Capability 7	48.0483		$2.31	4.81%	1.0000
8	Capability 8	48.4083		$3.34	6.89%	1.0000
9	Capability 9	20.0650		$0.77	3.82%	1.0000
10	Capability 10	26.7983		$1.62	6.03%	1.0000
11	Capability 11	18.7800		$1.33	7.07%	1.0000
12	Capability 12	21.8483		$2.48	11.37%	1.0000
13	Capability 13	22.1483		$0.90	4.08%	1.0000
14	Capability 14	40.2383		$3.85	9.56%	1.0000
15	Capability 15	14.7733		$0.89	6.03%	1.0000
16	Capability 16	14.1733		$1.16	8.16%	1.0000
17	Capability 17	27.0967		$1.23	4.54%	1.0000
18	Capability 18	13.2733		$0.49	3.72%	1.0000
19	Capability 19	9.5350		$0.32	3.40%	1.0000
20	Capability 20	14.7733		$0.24	1.64%	1.0000
21	Capability 21	15.6733		$0.71	4.54%	1.0000
22	Capability 22	13.3833		$0.63	4.68%	1.0000
23	Capability 23	9.2250		$0.56	6.03%	1.0000
	Total	584.66	$645.00	$12.49		23
	Constraints:	MAX	$150.00			10
	Sharpe Ratio	46.8161				

All Manual Permutations: 2.585E+22

Go and No-Go decisions on portfolio optimization

Benefits, cost, risk, EMV are all considered... additional constraints and variables can be easily added

Changing Constraints
(Markowitz Efficient Frontier)

Min	$150.00
Max	$300.00
Step	$25.00

Cost-Value Correlation
0.3592

Constraints can be set (e.g., budget, capability count, FTE, priorities, and new constraints can be quickly added)

Risk Simulator's Optimization Profile:

EMV ACB14 Cost Runs all 23 Capabilities to find the best combination of capabilities in ACB 14 subject to $150M Budget Constraint, Max EMV (Choose EMV Type)

Instructions: Reset all selections to 1 (H4:H26), select EMV type, click on Run Optimization!
Corresponding ROV Modeler file: 01 Discrete Optimization EMV (Functional Complexity Only) ACB14.ro
Corresponding ROV Modeler file: 02 Discrete Optimization EMV (Weighted and Common Sized) ACB14.ro
Corresponding ROV Modeler file: 03 Discrete Optimization EMV (Weighted) ACB14.ro

Figure 1. Portfolio Optimization Model

Figure 3 illustrates the portfolio optimization and capability selection setup using the Risk Simulator software. It shows Static and Dynamic Optimization routines run on multiple decision variables and constraints. It also shows the exact specifications of the model.

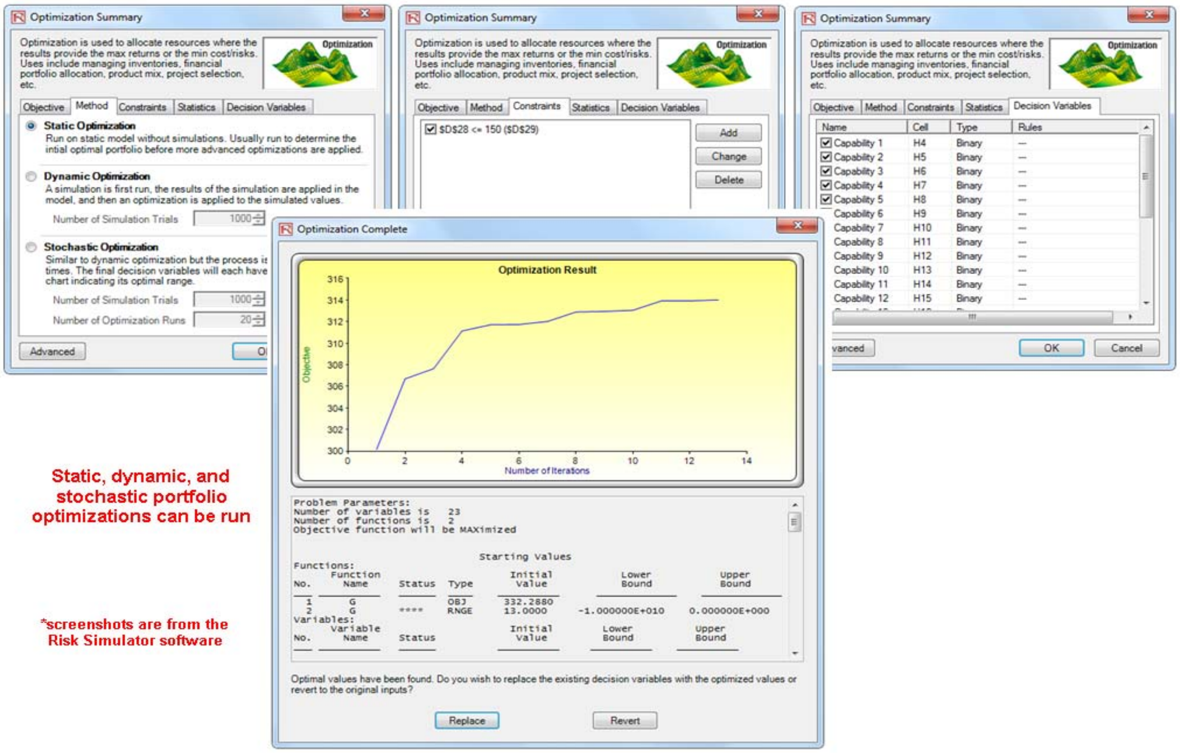


Figure 2. Optimization Model Setup in Risk Simulator

Expected Military Value (EMV)

The next step in the analysis was to apply the combination of 4 EMV methods to obtain the portfolio of options results and recommendations for sequencing capability insertions for ACB 14, ACB 16, and ACB 18. Figures 4 through 7 show the details of each portfolio optimization run and their corresponding capability set selected. The specification of each optimization depends on the EMV that is selected. For instance, the first set of results below is run based on using the mean of the subject-matter experts' (SME) value-added estimates, software lines of code (DSLOC), and OPNAV and technical priorities, and all these variables are combined through weighting and common-sizing the averages. The portfolio optimization is run to determine the best capabilities to select to maximize the total EMV for the portfolio, while at the same time maximizing the EMV, subject to the $150 million budget constraint. These results indicate a multi-criteria optimization routine, in which various objectives or EMVs are used in the portfolio-selection process.

Expected Military Value: SME Mean Value Added, DSLOC Complexity, Common Sized, Weighted OPNAV/Technical Priorities

	Capability	EMV	Cost	Risk $	Risk %	Selection
1	Capability 1	37.6800		$6.91	18.34%	0.0000
2	Capability 2	42.2350		$3.81	9.03%	0.0000
3	Capability 3	19.7800		$1.42	7.19%	0.0000
4	Capability 4	48.0417		$2.77	5.76%	1.0000
5	Capability 5	21.0733		$0.86	4.07%	1.0000
6	Capability 6	37.6033		$5.90	15.68%	0.0000
7	Capability 7	48.0483	Data Redacted	$2.31	4.81%	1.0000
8	Capability 8	48.4083		$3.34	6.89%	0.0000
9	Capability 9	20.0650		$0.77	3.82%	1.0000
10	Capability 10	26.7983		$1.62	6.03%	1.0000
11	Capability 11	18.7800		$1.33	7.07%	1.0000
12	Capability 12	21.8483		$2.48	11.37%	0.0000
13	Capability 13	22.1483		$0.90	4.08%	1.0000
14	Capability 14	40.2383		$3.85	9.56%	1.0000
15	Capability 15	14.7733		$0.89	6.03%	1.0000
16	Capability 16	14.1733		$1.16	8.16%	1.0000
17	Capability 17	27.0967		$1.23	4.54%	1.0000
18	Capability 18	13.2733		$0.49	3.72%	1.0000
19	Capability 19	9.5350		$0.32	3.40%	0.0000
20	Capability 20	14.7733		$0.24	1.64%	0.0000
21	Capability 21	15.6733		$0.71	4.54%	0.0000
22	Capability 22	13.3833		$0.63	4.68%	0.0000
23	Capability 23	9.2250		$0.56	6.03%	0.0000
	Total	314.51	$150.00	$6.18	Max EMV at $150M Budget	12
	Constraints:	MAX	$150.00			10
	Sharpe Ratio	50.8882				

Changing Constraints
(Markowitz Efficient Frontier)

Min	$150.00
Max	$300.00
Step	$25.00

Cost-Value Correlation
0.3592

Figure 3. ACB 14 Optimization Results

Expected Military Value: SME Mean Value Added, DSLOC Complexity, Common Sized, Weighted OPNAV/Technical Priorities

	Capability	EMV	Cost	Risk $	Risk %	Selection
1	Capability 1	37.6800		$6.91	18.34%	0.0000
2	Capability 2	42.2350		$3.81	9.03%	0.0000
3	Capability 3	19.7800		$1.42	7.19%	0.0000
4	Capability 4	48.0417		$2.77	5.76%	1.0000
5	Capability 5	21.0733		$0.86	4.07%	1.0000
6	Capability 6	37.6033		$5.90	15.68%	1.0000
7	Capability 7	48.0483		$2.31	4.81%	1.0000
8	Capability 8	48.4083	Data Redacted	$3.34	6.89%	0.0000
9	Capability 9	20.0650		$0.77	3.82%	0.0000
10	Capability 10	26.7983		$1.62	6.03%	1.0000
11	Capability 11	18.7800		$1.33	7.07%	1.0000
12	Capability 12	21.8483		$2.48	11.37%	0.0000
13	Capability 13	22.1483		$0.90	4.08%	1.0000
14	Capability 14	40.2383		$3.85	9.56%	1.0000
15	Capability 15	14.7733		$0.89	6.03%	1.0000
16	Capability 16	14.1733		$1.16	8.16%	0.0000
17	Capability 17	27.0967		$1.23	4.54%	1.0000
18	Capability 18	13.2733		$0.49	3.72%	0.0000
19	Capability 19	9.5350		$0.32	3.40%	0.0000
20	Capability 20	14.7733		$0.24	1.64%	0.0000
21	Capability 21	15.6733		$0.71	4.54%	0.0000
22	Capability 22	13.3833		$0.63	4.68%	0.0000
23	Capability 23	9.2250		$0.56	6.03%	0.0000
	Total	304.60	$150.00	$8.41	Max EMV, Budget and Capability Constraints	10
	Constraints:	MAX	$150.00			10
	Sharpe Ratio	36.2059				

Changing Constraints
(Markowitz Efficient Frontier)

Min	$150.00
Max	$300.00
Step	$25.00

Cost-Value Correlation
0.3592

Figure 4. ACB 14 Optimization Results II

Expected Military Value: SME Mean Value Added and DSLOC Complexity Only

	Capability	EMV	Cost	Risk $	Risk %	Selection
1	Capability 1	321.0000		$58.88	18.34%	0.0000
2	Capability 2	569.0000		$51.37	9.03%	0.0000
3	Capability 3	71.0000		$5.11	7.19%	0.0000
4	Capability 4	675.3333		$38.87	5.76%	1.0000
5	Capability 5	151.6667		$6.17	4.07%	0.0000
6	Capability 6	427.6667		$67.05	15.68%	1.0000
7	Capability 7	599.6667		$28.85	4.81%	1.0000
8	Capability 8	722.6667		$49.81	6.89%	0.0000
9	Capability 9	128.0000	Data	$4.89	3.82%	0.0000
10	Capability 10	222.6667	Redacted	$13.44	6.03%	1.0000
11	Capability 11	108.0000		$7.64	7.07%	1.0000
12	Capability 12	186.6667		$21.21	11.37%	0.0000
13	Capability 13	186.6667		$7.62	4.08%	1.0000
14	Capability 14	567.6667		$54.27	9.56%	1.0000
15	Capability 15	151.6667		$9.15	6.03%	1.0000
16	Capability 16	151.6667		$12.38	8.16%	1.0000
17	Capability 17	362.3333		$16.44	4.54%	1.0000
18	Capability 18	151.6667		$5.64	3.72%	1.0000
19	Capability 19	95.0000		$3.23	3.40%	0.0000
20	Capability 20	151.6667		$2.49	1.64%	0.0000
21	Capability 21	166.6667		$7.56	4.54%	0.0000
22	Capability 22	191.6667		$8.96	4.68%	0.0000
23	Capability 23	105.0000		$6.34	6.03%	0.0000
	Total	3605.00	$146.00	$103.05		11
	Constraints:	MAX	$150.00	Max EMV		10
	Sharpe Ratio	34.9815				

Changing Constraints
(Markowitz Efficient Frontier)
Min $150.00
Max $300.00
Step $25.00

Cost-Value Correlation
0.3857

Figure 5. ACB 14 Optimization Results III

Expected Military Value: OPNAV & Technical Priorities Only

	Capability	EMV	Cost	Risk $	Risk %	Selection
1	Capability 1	43.0000		$7.89	18.34%	0.0000
2	Capability 2	45.0000		$4.06	9.03%	0.0000
3	Capability 3	44.0000		$3.16	7.19%	0.0000
4	Capability 4	39.0000		$2.24	5.76%	1.0000
5	Capability 5	34.0000		$1.38	4.07%	1.0000
6	Capability 6	38.0000		$5.96	15.68%	1.0000
7	Capability 7	37.0000		$1.78	4.81%	1.0000
8	Capability 8	27.0000	Data	$1.86	6.89%	0.0000
9	Capability 9	32.0000	Redacted	$1.22	3.82%	1.0000
10	Capability 10	28.0000		$1.69	6.03%	1.0000
11	Capability 11	29.0000		$2.05	7.07%	1.0000
12	Capability 12	22.0000		$2.50	11.37%	0.0000
13	Capability 13	23.0000		$0.94	4.08%	1.0000
14	Capability 14	21.0000		$2.01	9.56%	0.0000
15	Capability 15	13.0000		$0.78	6.03%	1.0000
16	Capability 16	11.0000		$0.90	8.16%	1.0000
17	Capability 17	12.0000		$0.54	4.54%	1.0000
18	Capability 18	8.0000		$0.30	3.72%	1.0000
19	Capability 19	6.0000		$0.20	3.40%	0.0000
20	Capability 20	13.0000		$0.21	1.64%	0.0000
21	Capability 21	9.0000		$0.41	4.54%	0.0000
22	Capability 22	10.0000		$0.47	4.68%	0.0000
23	Capability 23	8.0000		$0.48	6.03%	0.0000
	Total	304.00	$150.00	$7.54		12
	Constraints:	MAX	$150.00	Max EMV		10
	Sharpe Ratio	40.3186				

Changing Constraints
(Markowitz Efficient Frontier)
Min $150.00
Max $300.00
Step $25.00

Cost-Value Correlation
0.4117

Figure 6. ACB 14 Optimization Results IV

Figure 8 summarizes the capabilities chosen based on each of the four EMV approaches, and the resultant recommendations for implementation. Specifically, the last column shows the optimal decision based on a portfolio of options of decisions. For instance, the following capabilities should be considered as optimal for ACB 14: Capabilities 4, 7, 10, 11, 13, 14, 15, 16, 17, and 18. Using the multi-criteria optimization, the analysis does not simply rely on a single estimate of EMV, but is able to employ the data from multiple facets and triangulate the best course of action. Figure 8 shows the results. It illustrates that certain components are always selected regardless of the EMV metric used, providing a higher level of comfort in the analysis, and these are the components we recommend (last column in the figure). Further, there are multiple components that 3 out of 4 of the optimization routines suggest executing; in most cases, these are not considered the top 10 components, but nonetheless important in the current ACB 14. These 4 EMV choices provide a view on the Analysis of Alternatives. The results of this analysis postulates which components are considered the top 10 and which are not, while still being critical in the ACB 14 portfolio. Using these four EMV options, we have four optimal portfolios, and we can quickly determine the best Course of Action (shown as the last column in Figure 8).

Discrete Optimization EMV (OPNAV and Technical Priorities Only) ACB14

Constraint Capability	SMEMVA, DSLOC, Priorities, Sized $150M	SMEMVA, DSLOC, Priorities, Sized $150M Top 10	SMEMVA, DSLOC $150M	Technical & OPNAV Priorities $150M	OPNAV Priority & DSLOC $150M	Recommendation Option 1 $134	Recommendation Option 2 146
Capability 1							
Capability 2							
Capability 3							
Capability 4	GO	GO	GO	GO	GO	1	1
Capability 5	GO	GO		GO	GO	1	
Capability 6		GO	GO	GO	GO		1
Capability 7	GO	GO	GO	GO	GO	1	1
Capability 8							
Capability 9	GO			GO	GO		
Capability 10	GO	GO	GO	GO	GO	1	1
Capability 11	GO	GO	GO	GO	GO	1	1
Capability 12							
Capability 13	GO	GO	GO	GO	GO	1	1
Capability 14	GO	GO	GO			1	1
Capability 15	GO	GO	GO	GO	GO	1	1
Capability 16	GO		GO	GO	GO	1	1
Capability 17	GO	GO	GO	GO	GO	1	1
Capability 18	GO		GO	GO	GO	1	1
Capability 19							
Capability 20							
Capability 21							
Capability 22							
Capability 23							

Figure 7. ACB 14 Portfolio of Options Results

Sequencing of ACB 14, ACB 16, ACB 18

The next step in the analysis was performing a sequential compound portfolio option by examining ACB 16 and ACB 18. In other words, based on the analysis for ACB1 4, the budget of no more than $150 million will be spent on 11 capabilities, with the remaining 12 capabilities still available for future execution. So, with another $150 million budget in ACB 16, the portfolio optimization was rerun with the truncated list of available capabilities, and the results shown in Figure 9 were obtained. The analysis considers capabilities that may not be available until later ACBs by simply including them in the process beginning with the earliest ACB for which they are ready for integration. The optimization is repeated based on each of the four multi-criteria objectives and provides a list of recommended capabilities to execute (highlighted box in Figure 10 shows the recommended components in this ACB).

Expected Military Value: SME Mean Value Added, DSLOC Complexity, Common Sized, Weighted OPNAV/Technical Priorities

	Capability	EMV	Cost	Risk $	Risk %	Selection	
1	Capability 1	37.6800		$6.91	18.34%	1.0000	ACB16
2	Capability 2	42.2350		$3.81	9.03%	0.0000	
3	Capability 3	19.7800		$1.42	7.19%	0.0000	
4	Capability 4	48.0417		$2.77	5.76%		ACB14
5	Capability 5	21.0733		$0.86	4.07%	1.0000	ACB16
6	Capability 6	37.6033		$5.90	15.68%		ACB14
7	Capability 7	48.0483		$2.31	4.81%		ACB14
8	Capability 8	48.4083	Data Redacted	$3.34	6.89%	0.0000	
9	Capability 9	20.0650		$0.77	3.82%	1.0000	ACB16
10	Capability 10	26.7983		$1.62	6.03%		ACB14
11	Capability 11	18.7800		$1.33	7.07%		ACB14
12	Capability 12	21.8483		$2.48	11.37%	1.0000	ACB16
13	Capability 13	22.1483		$0.90	4.08%		ACB14
14	Capability 14	40.2383		$3.85	9.56%		ACB14
15	Capability 15	14.7733		$0.89	6.03%		ACB14
16	Capability 16	14.1733		$1.16	8.16%		ACB14
17	Capability 17	27.0967		$1.23	4.54%		ACB14
18	Capability 18	13.2733		$0.49	3.72%		ACB14
19	Capability 19	9.5350		$0.32	3.40%	1.0000	ACB16
20	Capability 20	14.7733		$0.24	1.64%	1.0000	ACB16
21	Capability 21	15.6733		$0.71	4.54%	1.0000	ACB16
22	Capability 22	13.3833		$0.63	4.68%		ACB14
23	Capability 23	9.2250		$0.56	6.03%	1.0000	ACB16
	Total	149.87	$141.00	$7.50		8	
	Constraints:	MAX	$150.00			10	
	Sharpe Ratio	19.9844					

Figure 8. ACB 16 Optimization Results

Discrete Optimization EMV ACB16

SMEMVA, DSLOC, Priorities, Sized $150M	SMEMVA, DSLOC $150M	Technical & OPNAV Priorities $150M	OPNAV Priority & DSLOC $150M	Recommendation Option 1 $131
GO	GO	GO	GO	1
ACB14	ACB14	ACB15	ACB16	
GO		GO	GO	1
ACB14	ACB14	ACB14	ACB14	
ACB14	ACB14	ACB14	ACB14	
	GO			
GO		GO	GO	1
ACB14	ACB14	ACB14	ACB14	
ACB14	ACB14	ACB14	ACB14	
GO		GO	GO	1
ACB14	ACB14	ACB14	ACB14	
ACB14	ACB14	ACB14	ACB14	
ACB14	ACB14	ACB14	ACB14	
ACB14	ACB14	ACB14	ACB14	
ACB14	ACB14	ACB14	ACB14	
ACB14	ACB14	ACB14	ACB14	
GO		GO	GO	1
GO	GO	GO	GO	1
GO	GO	GO	GO	1
GO	GO	GO	GO	1

Figure 9. ACB 16 Portfolio of Options Results

The analysis continued with the portfolio optimization on ACB 18. The highlighted boxes in Figures 11 and 12 show the recommended component to execute in ACB 18, and in this case it is Capability 2. Capability 2 holds the highest OPNAV priority, but when the analysis includes the other inputs into the EMV metrics (DSLOC, Technical Priority, Weights, and SME Estimated Value-Add), and considers the high cost ($126 million) with respect to the allowed portfolio budget ($150 million), Capability 2 fails the selection for ACB 14 and ACB 16, and is only recommended in ACB 18. However, the analysis can consider alternate scenarios in which OPNAV Priority is taken as the most important criteria, and Capability 2 is specified as a “must-have” in ACB 14. The analysis was then rerun to determine the optimal portfolio given this new requirement. The results of that run are documented in the next section. The report next illustrates the effects on EMV of selecting Capability 2 in ACB 14 through to the year 2025. The report then continues with the Efficient Frontier analysis to show what additional components should be added in each ACB if additional budget is allocated (e.g., what if the budget were extended to $175 million or $200 million, and so forth, to determine at what point perhaps more critical components would have been selected). The optimization analysis is highly flexible to accommodate such alternate scenarios and requirements.

Expected Military Value: SME Mean Value Added, DSLOC Complexity, Common Sized, Weighted OPNAV/Technical Priorities

	Capability	EMV	Cost	Risk $	Risk %	Selection	
1	Capability 1	37.6800	Data Redacted	$6.91	18.34%		ACB16
2	Capability 2	42.2350		$3.81	9.03%	1.0000	ACB18
3	Capability 3	19.7800		$1.42	7.19%	0.0000	
4	Capability 4	48.0417		$2.77	5.76%		ACB14
5	Capability 5	21.0733		$0.86	4.07%		ACB16
6	Capability 6	37.6033		$5.90	15.68%		ACB14
7	Capability 7	48.0483		$2.31	4.81%		ACB14
8	Capability 8	48.4083		$3.34	6.89%	0.0000	
9	Capability 9	20.0650		$0.77	3.82%		ACB16
10	Capability 10	26.7983		$1.62	6.03%		ACB14
11	Capability 11	18.7800		$1.33	7.07%		ACB14
12	Capability 12	21.8483		$2.48	11.37%		ACB16
13	Capability 13	22.1483		$0.90	4.08%		ACB14
14	Capability 14	40.2383		$3.85	9.56%		ACB14
15	Capability 15	14.7733		$0.89	6.03%		ACB14
16	Capability 16	14.1733		$1.16	8.16%		ACB14
17	Capability 17	27.0967		$1.23	4.54%		ACB14
18	Capability 18	13.2733		$0.49	3.72%		ACB14
19	Capability 19	9.5350		$0.32	3.40%		ACB16
20	Capability 20	14.7733		$0.24	1.64%		ACB16
21	Capability 21	15.6733		$0.71	4.54%		ACB16
22	Capability 22	13.3833		$0.63	4.68%		ACB14
23	Capability 23	9.2250		$0.56	6.03%		ACB16
	Total	42.24	$126.00	$3.81		1	
	Constraints:	MAX	$150.00			10	
	Sharpe Ratio	11.0759					

Figure 10. ACB 18 Optimization Results

Discrete Optimization EMV ACB18

SMEMVA, DSLOC, Priorities, Sized $150M	SMEMVA, DSLOC $150M	Technical & OPNAV Priorities $150M	OPNAV Priority & DSLOC $150M	Recommendation Option 1 $126
ACB16	ACB16	ACB16	ACB16	
		GO	GO	1
ACB14	ACB14	ACB14	ACB14	
ACB16	ACB16	ACB16	ACB16	
ACB14	ACB14	ACB14	ACB14	
ACB14	ACB14	ACB14	ACB14	
GO	GO			
ACB16	ACB16	ACB16	ACB16	
ACB14	ACB14	ACB14	ACB14	
ACB14	ACB14	ACB14	ACB14	
ACB16	ACB16	ACB16	ACB16	
ACB14	ACB14	ACB14	ACB14	
ACB14	ACB14	ACB14	ACB14	
ACB14	ACB14	ACB14	ACB14	
ACB14	ACB14	ACB14	ACB14	
ACB14	ACB14	ACB14	ACB14	
ACB14	ACB14	ACB14	ACB14	
ACB16	ACB16	ACB16	ACB16	
ACB16	ACB16	ACB16	ACB16	
ACB16	ACB16	ACB16	ACB16	
ACB16	ACB16	ACB16	ACB16	

Figure 11. ACB 18 Portfolio of Options

Alternate Scenario: Capability 2 "Must-Have"

The optimization model and approach used is highly adaptive and flexible. The next analytic step conducted was the specification of one or more components as a "must have," specifically, Capability 2 was set as a mandatory capability for inclusion in ACB 14. Figure 13, illustrates the generation of an alternate scenario by applying OPNAV's Priority 1 on Capability 2 as a "must-have" in the portfolio selection and by identifying what other capabilities should be inserted in each ACB examined in such a scenario. When the integration budget is constrained to $150 million, if a significant portion of it is allocated to Capability 2, then only a little is left over for other components. Figure 13 shows what these components are (i.e., on the last column of Figure 13, the decision variable set as 1 indicates a "go" decision, whereas 0 indicates a "no-go").

Expected Military Value: SME Mean Value Added, DSLOC Complexity, Common Sized, Weighted OPNAV/Technical Priorities

	Capability	EMV	Cost	Risk $	Risk %	Selection	
1	Capability 1	37.6800		$6.91	18.34%	0.0000	
2	Capability 2	42.2350		$3.81	9.03%	1.0000	Capability 2 "Must Have"
3	Capability 3	19.7800		$1.42	7.19%	0.0000	
4	Capability 4	48.0417		$2.77	5.76%	0.0000	
5	Capability 5	21.0733		$0.86	4.07%	0.0000	
6	Capability 6	37.6033		$5.90	15.68%	0.0000	
7	Capability 7	48.0483		$2.31	4.81%	0.0000	
8	Capability 8	48.4083	Data Redacted	$3.34	6.89%	0.0000	
9	Capability 9	20.0650		$0.77	3.82%	0.0000	
10	Capability 10	26.7983		$1.62	6.03%	0.0000	
11	Capability 11	18.7800		$1.33	7.07%	1.0000	
12	Capability 12	21.8483		$2.48	11.37%	0.0000	
13	Capability 13	22.1483		$0.90	4.08%	0.0000	
14	Capability 14	40.2383		$3.85	9.56%	0.0000	
15	Capability 15	14.7733		$0.89	6.03%	0.0000	
16	Capability 16	14.1733		$1.16	8.16%	1.0000	
17	Capability 17	27.0967		$1.23	4.54%	1.0000	
18	Capability 18	13.2733		$0.49	3.72%	1.0000	
19	Capability 19	9.5350		$0.32	3.40%	0.0000	
20	Capability 20	14.7733		$0.24	1.64%	0.0000	
21	Capability 21	15.6733		$0.71	4.54%	0.0000	
22	Capability 22	13.3833		$0.63	4.68%	0.0000	
23	Capability 23	9.2250		$0.56	6.03%	0.0000	
	Total	115.56	$149.00	$4.40		5	
	Constraints:	MAX	$150.00			10	
	Sharpe Ratio	26.2374					

Figure 12. Capability 2 "Must-Have" in ACB 14

Aggregate EMV

By computing EMV accrued for each ACB, the analysis can then track the aggregation of value in terms of EMV available by ship-year based on the year of installation of each ACB in an individual ship. This approach permits representing the total capability available to the fleet as a single number. Figure 14 shows the ship availabilities for ACB insertions. Using this ship schedule and availability for ACB insertion and applying the optimal EMV values, the aggregate EMV values through the year 2025 become known (Figure 15). The second curve in Figure 15 demonstrates that EMV over time is marginally reduced by requiring Capability 2 to be included in ACB 14. Figure 15 also shows the "catch up" effect of the ACB process. Even though the introduction of a capability might be delayed from one ACB to the next, the total number of ships possessing the capability will become the same after the fourth ACB period if the delayed capability is included in the next update. An alternative to consider is to maintain the $150 million budget across all ACBs, but at the same time increase the ACB 14 budget to include a "special insertion budget" to cover Capability 2 and maintain the portfolio as suggested previously.

	A	H	I	J	K	L	M	N	O	P	Q	R	S	T
1														
2		YEAR IN PORT FOR AEGIS UPGRADE BASED ON 4 YEAR REFRESH CYCLE (TOTALS FOR EACH ACB AT BOTTOM)												
3		ACB 14	15	ACB 16	17	ACB 18	19	ACB 20	21	ACB 22	23	ACB 24	25	
4	SHIP ID													
5	CG52 - 1	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	511.52	4605.48
6	2	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	511.52	4604.48
7	3	0	0	383.59	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	4476.55
8	4	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4555.4
9	5	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4555.4
10	6	0	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4043.88
11	7	0	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4043.88
12	8	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	511.52	4604.48
13	9	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	511.52	4604.48
14	10	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	511.52	4604.48
15	11	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	511.52	4604.48
16	12	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	511.52	4604.48
17	13	0	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	4092.96
18	14	0	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	4092.96
19	15	0	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	4092.96
20	16	0	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	4092.96
21	17	0	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	4092.96
22	18	0	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	4092.96
23	19	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4554.4
24	20	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4554.4
25	21	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4554.4
26	22	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4554.4
27	23	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4554.4
28	24	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4554.4
29	25	0	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4042.88
30	26	0	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4042.88
31	27	0	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4042.88
32	28	0	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4042.88
33	29	0	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4042.88
34	30	0	115.56	115.56	115.56	115.56	511.52	511.52	511.52	511.52	511.52	511.52	511.52	4042.88
35	31	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	511.52	4603.48
36	32	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	511.52	4603.48
37	33	0	0	383.59	383.59	383.59	383.59	511.52	511.52	511.52	511.52	511.52	511.52	4603.48

Figure 13. ACB 14 Ship Availabilities

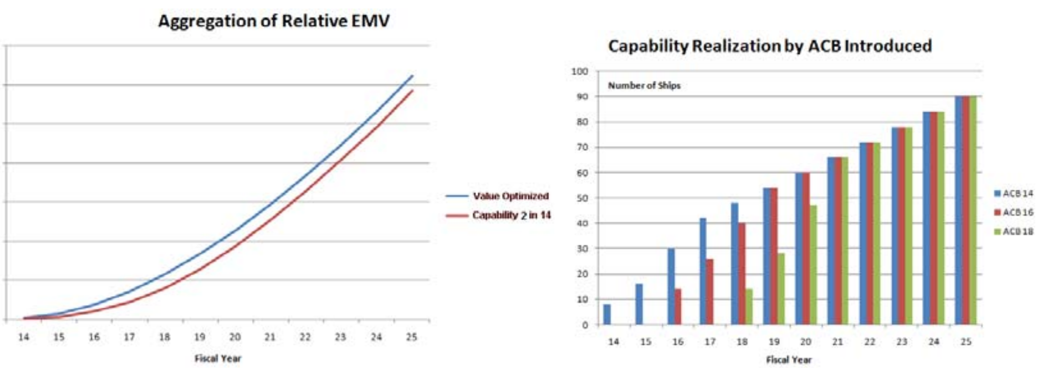


Figure 14. ACB 14 Aggregate EMV

Monte Carlo Risk Simulation

Monte Carlo Risk Simulation of cost estimates is used to determine the risk of budget and cost overruns (project timing overruns can also be determined if required). A sample of the simulated risk analysis results is shown in Figure 16. While capability selection is the key question addressed in this study, the risk analysis results are necessary and support some of the optimization analysis. For future modeling and decision-analysis work, the proper determination of appropriate risk measures, potentially including cost, schedule, technology, and other risks, would be appropriate and beneficial. The analyst can model all these uncertainties using the Risk Simulator software tools. Instead of relying on single-point estimates for cost and scheduled completion times, distributions of cost and time through expert estimates, comparable historical data, and expectations of high, most-likely, and low estimates for each input should be employed. The analytic method then specifies that these values be simulated thousands of times with the software to generate all possible outcomes and scenarios, and the results are then interpreted to examine the risks inherent in each ACB insertion. Applying this method to the first analysis, the results indicate that although the expected total cost is $150 million, there is 83.30% chance that the budget will be exceeded. In fact, to be 99% sure that there is sufficient money to cover the potential cost-creep, the budget would have to be increased to $171 million, indicating the need of a $21 million cushion. Similarly, the analyst can apply the methodology to determine the probability of the occurrence of schedule overruns. Other risks, such as technology risk, may be expressed in other ways to provide inputs to the simulator software.

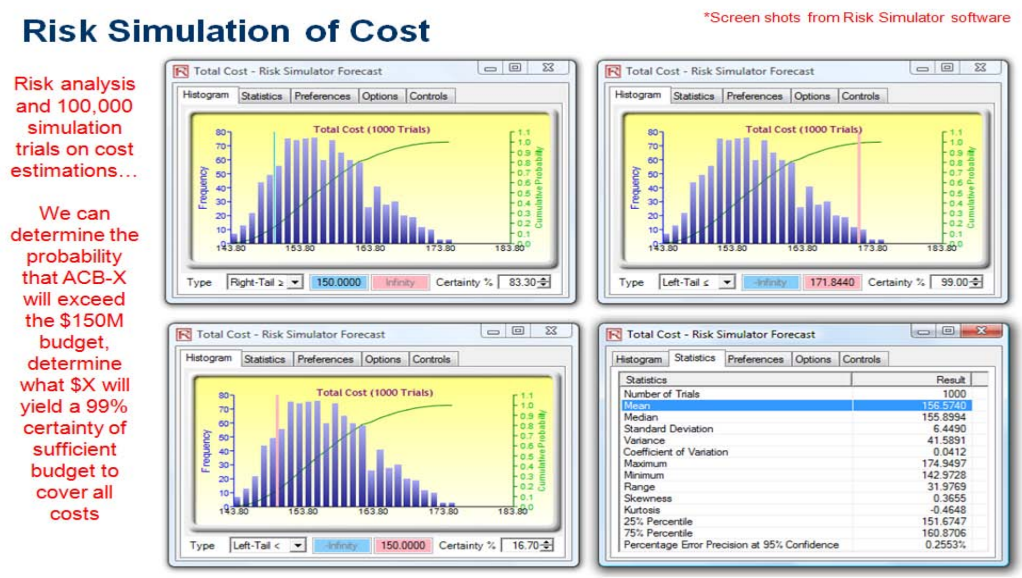


Figure 15. Risk Analysis on Cost for ACB 14

Portfolio Optimization’s Efficient Frontier

The portfolio Efficient Frontier analysis determines multiple scenarios of increasing budget (i.e., if the $150 million budget were increased to $200 million, or $250 million, or $300 million, and so forth, in various increments, what will the optimal portfolio look like; what capabilities should be added or replaced; and what are the impacts on EMV?). This analysis provides useful input for deliberations with the sponsor early in the budget-development process and yields data-driven sets of alternatives for various levels of funding.

Running the optimization procedure yields an optimal portfolio of projects in which the constraints are satisfied. This represents a single optimal portfolio point on the Efficient Frontier—for example, Portfolio B on the Efficient Frontier chart in Figure 17. Then, by subsequently changing some of the constraints—for instance, by increasing the budget—the analyst can rerun the optimization to produce another optimal portfolio given these new constraints. Therefore, a series of optimal portfolio allocations can be determined and graphed. This graphical representation of all optimal portfolios is called the portfolio’s Efficient Frontier. At this juncture, each point represents a portfolio allocation. For instance, Portfolio B might represent capabilities 1, 2, 5, 6, 7, 8, 10, 15, and so forth, while Portfolio C might represent capabilities 2, 6, 7, 9, 12, 15, and so forth—each resulting in different EMV, tactical, military, or comprehensive scores, and portfolio returns. It is up to the decision-maker to decide which portfolio represents the best decision and if sufficient resources exist to execute these projects. Typically, in an Efficient Frontier analysis, a decision-maker would select projects for which the marginal increase in benefits is positive, and the slope is steep. In the next example, that decision-maker would rather select Portfolio D rather than Portfolio E, as the marginal increase is negative on the y-axis (e.g., EMV). That is, spending too much money may actually reduce the overall EMV; hence, this portfolio should not be selected. Also, in comparing Portfolios A and B, a decision-maker would be more inclined to choose B, as the slope is steep and the same increase in budget requirements (x-axis) would return a much higher percentage EMV (y-axis). The decision to choose between Portfolios C and D would depend on available resources, and the decision-maker must decide if the added benefits warrant and justify the added budget and costs. Figures 18 through 22 illustrate the results from the Efficient Frontier analysis by changing the budget constraint from $150 million to $300 million by incrementing it $25 million in each step.

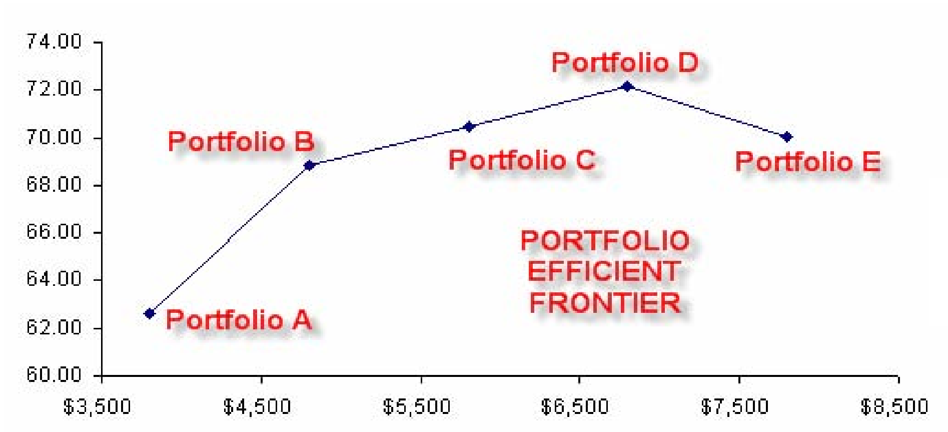


Figure 16. The Theory of Portfolio Efficient Frontier

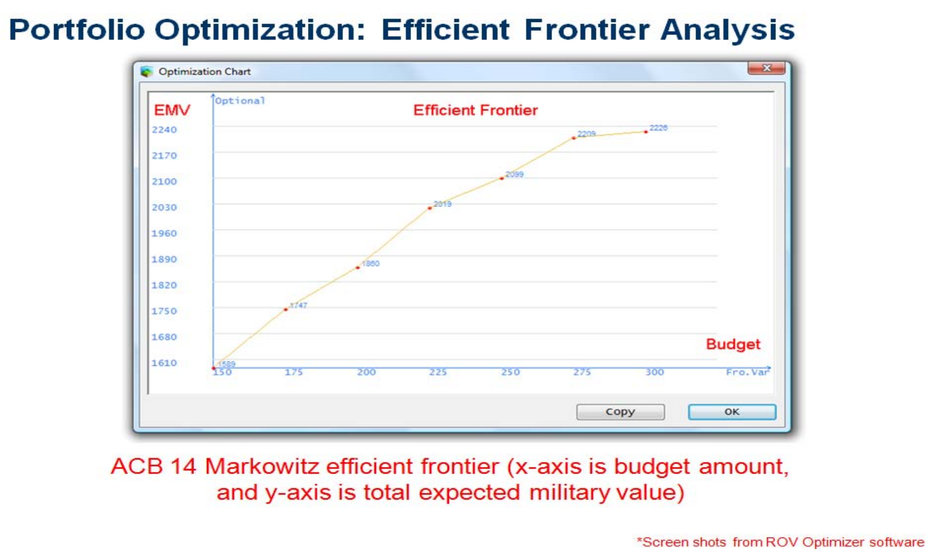


Figure 17. Portfolio Efficient Frontier

Discrete Optimization EMV (OPNAV and Technical Priorities Only) ACB14

Constraint	$150M	$175M	$200M	$225M	$250M	$275M	$300M
Expected Cost	$146M	$173M	$200M	$224M	$224M	$224M	
Capability 1	GO	GO	GO	GO	GO	GO	GO
Capability 2							
Capability 3							
Capability 4	GO	GO	GO	GO	GO	GO	GO
Capability 5	GO	GO	GO	GO	GO	GO	GO
Capability 6		GO	GO	GO	GO	GO	GO
Capability 7	GO	GO	GO	GO	GO	GO	GO
Capability 8							
Capability 9	GO	GO	GO	GO	GO	GO	GO
Capability 10	GO	GO	GO	GO	GO	GO	GO
Capability 11	GO	GO	GO	GO	GO	GO	GO
Capability 12			GO	GO	GO	GO	GO
Capability 13	GO	GO	GO	GO	GO	GO	GO
Capability 14							GO
Capability 15	GO	GO	GO	GO	GO	GO	GO
Capability 16	GO	GO	GO	GO	GO	GO	GO
Capability 17	GO	GO	GO	GO	GO	GO	GO
Capability 18			GO	GO	GO	GO	GO
Capability 19							
Capability 20				GO	GO	GO	GO
Capability 21							GO
Capability 22							
Capability 23				GO	GO	GO	GO

Figure 18. Efficient Frontier with Additional Budget Allocation I

Optimization EMV (SMEMVA DSLOC Weighted, Common Sized, Priorities) ACB14 Efficient

Constraint	$150M	$175M	$200M	$225M	$250M	$275M	$300M
Capability	$150M	$175M	$200M	$200M	$248M	$269M	$287M
Capability 1		GO	GO	GO	GO	GO	GO
Capability 2							
Capability 3							
Capability 4	GO	GO	GO	GO	GO	GO	GO
Capability 5	GO		GO	GO	GO	GO	GO
Capability 6		GO	GO	GO	GO	GO	GO
Capability 7	GO	GO	GO	GO	GO	GO	GO
Capability 8							
Capability 9	GO				GO	GO	GO
Capability 10	GO	GO	GO	GO	GO	GO	GO
Capability 11	GO	GO	GO	GO	GO	GO	GO
Capability 12						GO	GO
Capability 13	GO	GO	GO	GO	GO	GO	GO
Capability 14	GO	GO	GO	GO	GO	GO	GO
Capability 15	GO	GO	GO	GO	GO	GO	GO
Capability 16	GO	GO	GO	GO	GO	GO	GO
Capability 17	GO	GO	GO	GO	GO	GO	GO
Capability 18	GO	GO	GO	GO	GO	GO	GO
Capability 19							GO
Capability 20					GO	GO	GO
Capability 21					GO	GO	GO
Capability 22							
Capability 23			GO	GO	GO	GO	GO

Figure 19. Efficient Frontier with Additional Budget Allocation II

Discrete Optimization EMV (SMEMVA DSLOC Only) ACB14 Efficient Frontier

Constraint	$150M	$175M	$200M	$225M	$250M	$275M	$300M
Capability	$146M	$175M	$199M	$225M	$225M	$225M	$299M
Capability 1		GO	GO	GO	GO	GO	GO
Capability 2							
Capability 3							
Capability 4	GO	GO	GO	GO	GO	GO	GO
Capability 5				GO	GO	GO	GO
Capability 6	GO	GO	GO	GO	GO	GO	GO
Capability 7	GO	GO	GO	GO	GO	GO	GO
Capability 8							GO
Capability 9							
Capability 10	GO	GO	GO	GO	GO	GO	GO
Capability 11	GO	GO	GO	GO	GO	GO	GO
Capability 12				GO	GO	GO	
Capability 13	GO	GO	GO	GO	GO	GO	GO
Capability 14	GO	GO	GO	GO	GO	GO	GO
Capability 15	GO	GO	GO	GO	GO	GO	GO
Capability 16	GO	GO	GO	GO	GO	GO	GO
Capability 17	GO	GO	GO	GO	GO	GO	GO
Capability 18	GO	GO	GO	GO	GO	GO	GO
Capability 19							
Capability 20			GO	GO	GO	GO	GO
Capability 21							GO
Capability 22							
Capability 23			GO				

Figure 20. Efficient Frontier with Additional Budget Allocation III

Discrete Optimization EMV (OPNAV DSLOC Only) ACB14 Efficient Frontier

Constraint	$150M	$175M	$200M	$225M	$250M	$275M	$300M
Capability	$146M	$175M	$200M	$200M	$200M	$269M	$297M
Capability 1		GO	GO	GO	GO	GO	GO
Capability 2							
Capability 3							
Capability 4	GO	GO	GO	GO	GO	GO	GO
Capability 5	GO		GO	GO	GO	GO	GO
Capability 6	GO	GO	GO	GO	GO	GO	GO
Capability 7	GO	GO	GO	GO	GO	GO	GO
Capability 8							GO
Capability 9	GO		GO	GO	GO	GO	GO
Capability 10	GO	GO	GO	GO	GO	GO	GO
Capability 11	GO	GO	GO	GO	GO	GO	GO
Capability 12						GO	
Capability 13	GO	GO	GO	GO	GO	GO	GO
Capability 14		GO	GO	GO	GO	GO	GO
Capability 15	GO	GO	GO	GO	GO	GO	GO
Capability 16	GO	GO	GO	GO	GO	GO	GO
Capability 17	GO	GO	GO	GO	GO	GO	GO
Capability 18	GO	GO				GO	GO
Capability 19							
Capability 20						GO	GO
Capability 21						GO	
Capability 22							
Capability 23						GO	

Figure 21. Efficient Frontier with Additional Budget Allocation IV

Optimization with a Risk Constraint

Figure 23 shows an example optimization run in which we can set cost as the stochastic constraint. That is, seeing that cost overruns typically occur in development, we can set the risk simulation optimization combination model such that we want a portfolio where there is a 90% probability that the $150 million budget is not exceeded. In this sample run, we see that this can be accomplished by replacing Capability 9 with Capability 23, at a lower cost, thereby still creating the maximum EMV possible while maintaining a 90% probability that total portfolio cost will be under the required $150 million budget constraint. Alternatively, as shown previously in Figure 16, if the optimal portfolio is still desirable, then the $150 million budget needs to account for a potential overrun of $22 million. That is, there is a 99% probability that the total portfolio budget will be under $172 million. There is clearly a risk-value tradeoff occurring in this situation; the higher the probability of lower budget overruns, the lower the anticipated EMV. This tradeoff is also seen very clearly in the Efficient Frontier analysis, in which the results demonstrate that the higher the budget allocation, the greater the EMV. The final step in the analysis was a sample run with ACB 14, 16, and 18 based on the EMV applying all input assumptions, and with the additional contingent constraint the total budget used will not exceed $150 million for each ACB for at least 85% of the time. The results are shown in Figures 24, 25, and 26 for each of the ACBs sequenced. The resulting budget overrun risks are depicted in Figure 27. When this constraint is applied, the analysis yields a different portfolio selection for each ACB, and the probability of ***not*** exceeding the requisite $150 million budget becomes 97.99%, 90.90% and 99.99% for the three ACB years. Running the model with Capability 2 as mandatory in ACB 14 and applying the risk constraint, generates yet another set of selections, yielding confidence levels of not exceeding the budget of $150 million. Figure 28 shows the resulting aggregate EMV across all ships, revised to include the risk-cost portfolio. It is clear that the opportunity cost of applying the risk constraint, while measurable, is minimal ***for this case*** and actually represents less reduction in EMV overall than does the mandatory selection of a capability.

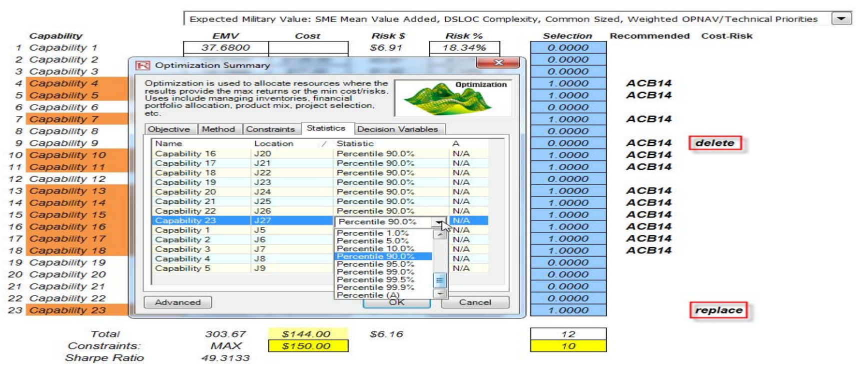


Figure 22. Cost-based Risk Optimization Alternative

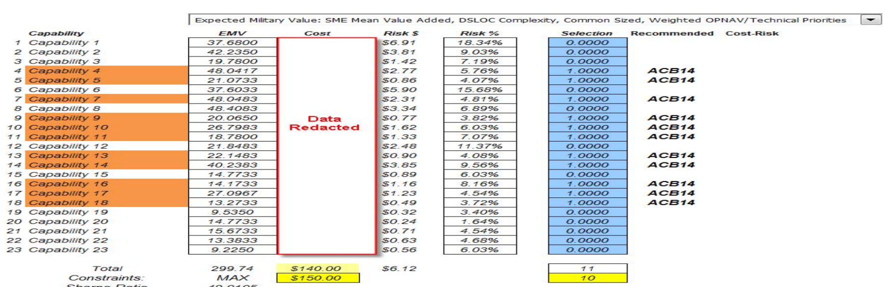


Figure 23. Cost-based Risk Optimization for ACB 14

Expected Military Value: SME Mean Value Added, DSLOC Complexity, Common Sized, Weighted OPNAV/Technical Priorities

	Capability	EMV	Cost	Risk $	Risk %	Selection	Recommended	Cost-Risk
1	Capability 1	37.6800		$6.91	18.34%	1.0000	ACB16	Cost Risk
2	Capability 2	42.2350		$3.81	9.03%	0.0000		
3	Capability 3	19.7800		$1.42	7.19%	0.0000		
4	Capability 4	48.0417		$2.77	5.76%			
5	Capability 5	21.0733		$0.86	4.07%			
6	Capability 6	37.6033		$5.90	15.68%	1.0000	ACB16	Cost Risk
7	Capability 7	48.0483		$2.31	4.81%			
8	Capability 8	48.4083		$3.34	6.89%	0.0000		
9	Capability 9	20.0650	Data Redacted	$0.77	3.82%			
10	Capability 10	26.7983		$1.62	6.03%			
11	Capability 11	18.7800		$1.33	7.07%			
12	Capability 12	21.8483		$2.48	11.37%	1.0000	ACB16	Cost Risk
13	Capability 13	22.1483		$0.90	4.08%			
14	Capability 14	40.2383		$3.85	9.56%			
15	Capability 15	14.7733		$0.89	6.03%	1.0000	ACB16	Cost Risk
16	Capability 16	14.1733		$1.16	8.16%			
17	Capability 17	27.0967		$1.23	4.54%			
18	Capability 18	13.2733		$0.49	3.72%			
19	Capability 19	9.5350		$0.32	3.40%	0.0000		
20	Capability 20	14.7733		$0.24	1.64%	1.0000	ACB16	Cost Risk
21	Capability 21	15.6733		$0.71	4.54%	1.0000	ACB16	Cost Risk
22	Capability 22	13.3833		$0.63	4.68%	0.0000		
23	Capability 23	9.2250		$0.56	6.03%	1.0000	ACB16	Cost Risk
	Total	151.58	$129.00	$9.51		7		
	Constraints:	MAX	$150.00			10		
	Sharpe Ratio	15.9455						

Figure 24. Cost-based Risk Optimization for ACB 16

Expected Military Value: SME Mean Value Added, DSLOC Complexity, Common Sized, Weighted OPNAV/Technical Priorities

	Capability	EMV	Cost	Risk $	Risk %	Selection	Recommended	Cost-Risk
1	Capability 1	37.6800		$6.91	18.34%	ACB16		
2	Capability 2	42.2350		$3.81	9.03%	0.0000		
3	Capability 3	19.7800		$1.42	7.19%	0.0000		
4	Capability 4	48.0417		$2.77	5.76%	ACB14		
5	Capability 5	21.0733		$0.86	4.07%	ACB14		
6	Capability 6	37.6033		$5.90	15.68%	ACB16		
7	Capability 7	48.0483		$2.31	4.81%	ACB14		
8	Capability 8	48.4083		$3.34	6.89%	1.0000	ACB18	Cost Risk
9	Capability 9	20.0650	Data Redacted	$0.77	3.82%	ACB14		
10	Capability 10	26.7983		$1.62	6.03%	ACB14		
11	Capability 11	18.7800		$1.33	7.07%	ACB14		
12	Capability 12	21.8483		$2.48	11.37%	ACB16		
13	Capability 13	22.1483		$0.90	4.08%	ACB14		
14	Capability 14	40.2383		$3.85	9.56%	ACB14		
15	Capability 15	14.7733		$0.89	6.03%	ACB16		
16	Capability 16	14.1733		$1.16	8.16%	ACB14		
17	Capability 17	27.0967		$1.23	4.54%	ACB14		
18	Capability 18	13.2733		$0.49	3.72%	ACB14		
19	Capability 19	9.5350		$0.32	3.40%	1.0000	ACB18	Cost Risk
20	Capability 20	14.7733		$0.24	1.64%	ACB16		
21	Capability 21	15.6733		$0.71	4.54%	ACB16		
22	Capability 22	13.3833		$0.63	4.68%	0.0000		
23	Capability 23	9.2250		$0.56	6.03%	ACB16		
	Total	57.94	$95.00			2		
	Constraints:	MAX	$150.00			10		

Figure 25. Cost-based Risk Optimization for ACB 18

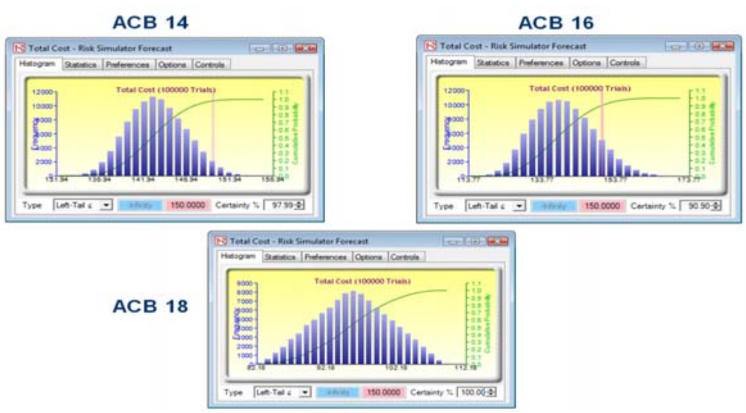


Figure 26. Cost-Risk Probabilities for ACB 14, 16, and 18

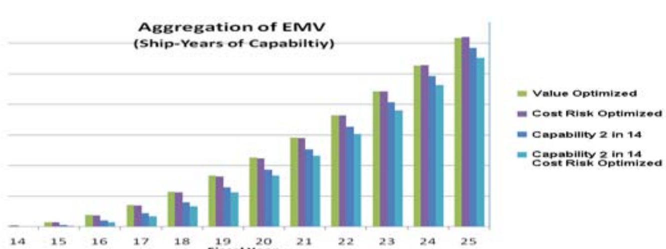


Figure 27. Aggregate EMV for 2014–2025

Figures 29 and 30 summarize the results of all portfolio runs as a simple visual matrix and list of summary statistics. The portfolio runs' visual matrix of results consists of four columns of portfolios: (1) optimization based on the required total budget of $150 million, assuming all costs are exact and have no risk (Optimal on Budget); (2) cost with uncertainty and risk that there will be budget overruns—with an added constraint of a portfolio with no more than 15% probability of a budget overrun, or 85% probability or higher, that the total budget of $150 million will not be exceeded (Optimal Cost-Risk); (3) Capability 2 is a required component in ACB 14 (Capability 2 Must-Have); and (4) Capability 2 as a Must-Have in ACB 14, with the added assumption of cost-risk as defined above (Capability 2 Cost-Risk). Similar ACB years are color-coded (e.g., green for ACB 14, blue for ACB 16, orange for ACB 18, and red for components that are not selected in these three ACBs, allowing for potential implementation later).

Figure 30 shows the summary key statistics of these portfolios, listing the number of capabilities implemented in each ACB cycle, the total expected budget used, the total EMV, and the probability that the ACB will be under budget. Clearly, the non-Cost-Risk portfolios bear higher total implementation costs with higher EMVs (high risk means high returns); however, the probability of being under budget is low, and the probability the budget will be exceeded is high. In this First Phase analysis, due to the analysis being run on only 23 capabilities, as expected, the EMVs are reallocated over time in various amounts (e.g., Capability 2 must-have will yield a smaller initial EMV due to the higher cost and moderate EMV value of executing Capability 2, but the catch-up happens in the subsequent ACBs). Figure 30 also examines the risk distribution of the budget based on the different portfolio criteria. For instance, we see that if we apply the value optimization without regard to the risk of cost overruns the median (or 50th percentile) budget is $153.2 million, above the budget constraint of $150 million. Alternatively, if we consider the risk of cost overruns, the median is only $142.9 million, providing a buffer for any overruns. In fact, we see that the 85th percentile is $146.6 million, and the 95th percentile is 148.7 million—both under the required $150 million. Further, there is a 97.90% probability that this portfolio will come in under the $150 million budget (for the sake of clarity, these values are highlighted in yellow in Figure 31). To reduce and hedge the risk of cost overruns—the expected budget used is less ($139 million as opposed to $146 million), with a return on EMV that is also less (310.98 as compared to 299.74). Therefore, to hedge and reduce the risk of cost overrun, the Navy spends less and gets less. This can be viewed as keeping some of the budget aside for the worst case scenario—therefore leaving less money available to invest in additional capabilities (the remaining statistics are fairly self-explanatory). One alternative to utilizing the highest number of capabilities, maximizing the EMV, and yet coming under budget, is to consider strategic real options in contract negotiations.

Decision-makers should exercise caution in the use of risk constraints to restrict consideration of portfolios. Blind selection of a risk-limited portfolio may result in excessive opportunity cost if other means exist to reduce risk in the input data. For example, better cost estimates in one or more of the components would reduce volatility in that component and, thereby, make it less likely to be excluded due to a high contribution to aggregate risk. Similarly, altering the cost profile through risk mitigation efforts in the contract structure (caps, fixed-price provisions, etc.) changes the input and will change the output from the model. By applying the appropriate risk-mitigation measures and by rerunning the analysis, decision-makers may provide a better portfolio selection than simply constraining the analysis through applying a risk cap. Intelligent use of the toolset as a decision aid maximizes its value to the manager.

ACB 14 + ACB 16 + ACB 18 **Capability**	Optimal on Budget	Optimal Cost-Risk	Capability 2 Must-Have	Capability 2 Cost-Risk
Capability 1	ACB16	ACB16	ACB16	ACB18
Capability 2	ACB18	Later	ACB14	ACB14
Capability 3	Later	Later	Later	Later
Capability 4	ACB14	ACB14	ACB16	ACB16
Capability 5	ACB16	ACB14	ACB16	ACB16
Capability 6	ACB14	ACB16	ACB18	ACB18
Capability 7	ACB14	ACB14	ACB16	ACB16
Capability 8	Later	ACB18	ACB18	Later
Capability 9	ACB16	ACB14	ACB18	ACB16
Capability 10	ACB14	ACB14	ACB16	ACB16
Capability 11	ACB14	ACB14	ACB14	ACB14
Capability 12	ACB16	ACB16	ACB18	ACB18
Capability 13	ACB14	ACB14	ACB16	ACB16
Capability 14	ACB14	ACB14	ACB16	ACB16
Capability 15	ACB14	ACB16	ACB16	ACB18
Capability 16	ACB14	ACB14	ACB14	ACB16
Capability 17	ACB14	ACB14	ACB14	ACB16
Capability 18	ACB14	ACB14	ACB14	ACB16
Capability 19	ACB16	ACB18	Later	Later
Capability 20	ACB16	ACB16	Later	ACB18
Capability 21	ACB16	ACB16	Later	ACB18
Capability 22	Later	Later	Later	Later
Capability 23	ACB16	ACB16	ACB16	ACB18

Figure 28. Summary of All Sequenced and Optimized Portfolios

ACB 14 + ACB 16 + ACB 18 *rounded to the nearest 0.1	Optimal on Budget	Optimal Cost-Risk	Capability 2 Must-Have	Capability 2 Cost-Risk
Total Capabilities ACB14	11	11	5	2
Total Capabilities ACB16	8	7	9	10
Total Capabilities ACB18	1	2	4	7
EMV ACB14	310.98	299.74	115.56	61.02
EMV ACB16	149.87	151.58	268.03	280.96
EMV ACB18	42.24	57.94	127.93	151.58
Total Cost ACB14	$146.00	$139.00	$149.00	$129.00
Total Cost ACB16	$141.00	$129.00	$150.00	$137.00
Total Cost ACB18	$126.00	$95.00	$141.00	$129.00
Total Spent on ACB14-18	$413.00	$363.00	$440.00	$395.00
Probability of Under Budget ACB14	29.70%	97.90%	41.50%	90.80%
Probability of Under Budget ACB16	72.23%	90.90%	16.25%	99.90%
Probability of Under Budget ACB18	94.80%	99.90%	72.90%	90.90%
ACB14 Median 50th Percentile on Budget	$153.20	$142.90	$152.60	$132.30
ACB14 Median 85th Percentile on Budget	$160.22	$146.60	$166.60	$146.30
ACB14 Median 95th Percentile on Budget	$164.30	$148.70	$173.90	$153.50
ACB16 Median 50th Percentile on Budget	$145.40	$137.90	$156.50	$139.50
ACB16 Median 85th Percentile on Budget	$153.50	$147.30	$164.80	$143.30
ACB16 Median 95th Percentile on Budget	$157.80	$152.70	$169.20	$145.30
ACB18 Median 50th Percentile on Budget	$128.90	$95.30	$145.10	$137.90
ACB18 Median 85th Percentile on Budget	$142.90	$101.30	$153.50	$147.30
ACB18 Median 95th Percentile on Budget	$150.20	$104.30	$158.40	$152.70

Figure 29. Summary of All Sequenced and Optimized Portfolios' Summary Statistics

2003 - 2010 Sponsored Research Topics

Acquisition Management

- Acquiring Combat Capability via Public-Private Partnerships (PPPs)
- BCA: Contractor vs. Organic Growth
- Defense Industry Consolidation
- EU-US Defense Industrial Relationships
- Knowledge Value Added (KVA) + Real Options (RO) Applied to Shipyard Planning Processes
- Managing the Services Supply Chain
- MOSA Contracting Implications
- Portfolio Optimization via KVA + RO
- Private Military Sector
- Software Requirements for OA
- Spiral Development
- Strategy for Defense Acquisition Research
- The Software, Hardware Asset Reuse Enterprise (SHARE) repository

Contract Management

- Commodity Sourcing Strategies
- Contracting Government Procurement Functions
- Contractors in 21st-century Combat Zone
- Joint Contingency Contracting
- Model for Optimizing Contingency Contracting, Planning and Execution
- Navy Contract Writing Guide
- Past Performance in Source Selection
- Strategic Contingency Contracting
- Transforming DoD Contract Closeout
- USAF Energy Savings Performance Contracts
- USAF IT Commodity Council
- USMC Contingency Contracting

Financial Management

- Acquisitions via Leasing: MPS case
- Budget Scoring
- Budgeting for Capabilities-based Planning

- Capital Budgeting for the DoD
- Energy Saving Contracts/DoD Mobile Assets
- Financing DoD Budget via PPPs
- Lessons from Private Sector Capital Budgeting for DoD Acquisition Budgeting Reform
- PPPs and Government Financing
- ROI of Information Warfare Systems
- Special Termination Liability in MDAPs
- Strategic Sourcing
- Transaction Cost Economics (TCE) to Improve Cost Estimates

Human Resources

- Indefinite Reenlistment
- Individual Augmentation
- Learning Management Systems
- Moral Conduct Waivers and First-tem Attrition
- Retention
- The Navy's Selective Reenlistment Bonus (SRB) Management System
- Tuition Assistance

Logistics Management

- Analysis of LAV Depot Maintenance
- Army LOG MOD
- ASDS Product Support Analysis
- Cold-chain Logistics
- Contractors Supporting Military Operations
- Diffusion/Variability on Vendor Performance Evaluation
- Evolutionary Acquisition
- Lean Six Sigma to Reduce Costs and Improve Readiness
- Naval Aviation Maintenance and Process Improvement (2)
- Optimizing CIWS Lifecycle Support (LCS)
- Outsourcing the Pearl Harbor MK-48 Intermediate Maintenance Activity
- Pallet Management System
- PBL (4)
- Privatization-NOSL/NAWCI
- RFID (6)

- Risk Analysis for Performance-based Logistics
- R-TOC AEGIS Microwave Power Tubes
- Sense-and-Respond Logistics Network
- Strategic Sourcing

Program Management

- Building Collaborative Capacity
- Business Process Reengineering (BPR) for LCS Mission Module Acquisition
- Collaborative IT Tools Leveraging Competence
- Contractor vs. Organic Support
- Knowledge, Responsibilities and Decision Rights in MDAPs
- KVA Applied to AEGIS and SSDS
- Managing the Service Supply Chain
- Measuring Uncertainty in Earned Value
- Organizational Modeling and Simulation
- Public-Private Partnership
- Terminating Your Own Program
- Utilizing Collaborative and Three-dimensional Imaging Technology

A complete listing and electronic copies of published research are available on our website: www.acquisitionresearch.org

THIS PAGE INTENTIONALLY LEFT BLANK

Acquisition Research Program:
Creating Synergy for Informed Change

Advanced Capability Builds for Aegis:

Stochastic Portfolio Optimization (Selection and Prioritization), Risk Simulation, KVA, and Strategic Real Options

Dr. Johnathan Mun
Naval Postgraduate School

Dr. Thomas Housel
Naval Postgraduate School

CAPT Mark Wessman USN (Ret)
Wessman Consultancy Group, Inc.

Introduction and Context

- **Introduction of Open Architecture (OA) business and technical processes provides opportunity to improve acquisition**
  - **Increased competition**
  - **Shorter cycle time**
  - **Reduced total ownership and acquisition cost**
- **The AEGIS Advanced Capability Build (ACB) process is one implementation of the OA approach**

The ACB Process

- The ACB process provides for software updates to ships within the program on a two-year cycle
- ACBs are identified by the first year in which they will be fielded, e.g., ACB-14
- US Navy CGs and DDGs will be inducted into the process as they receive computing plant updates during major availabilities that convert the processors and networks to a COTS-based configuration
- The hardware baseline that supports OA must be in place to begin execution of the ACB process
- Once a ship is inducted, it will receive the scheduled update plus any previous updates (e.g., ACB 16 ships entering the program will receive ACB 14 capabilities as well)

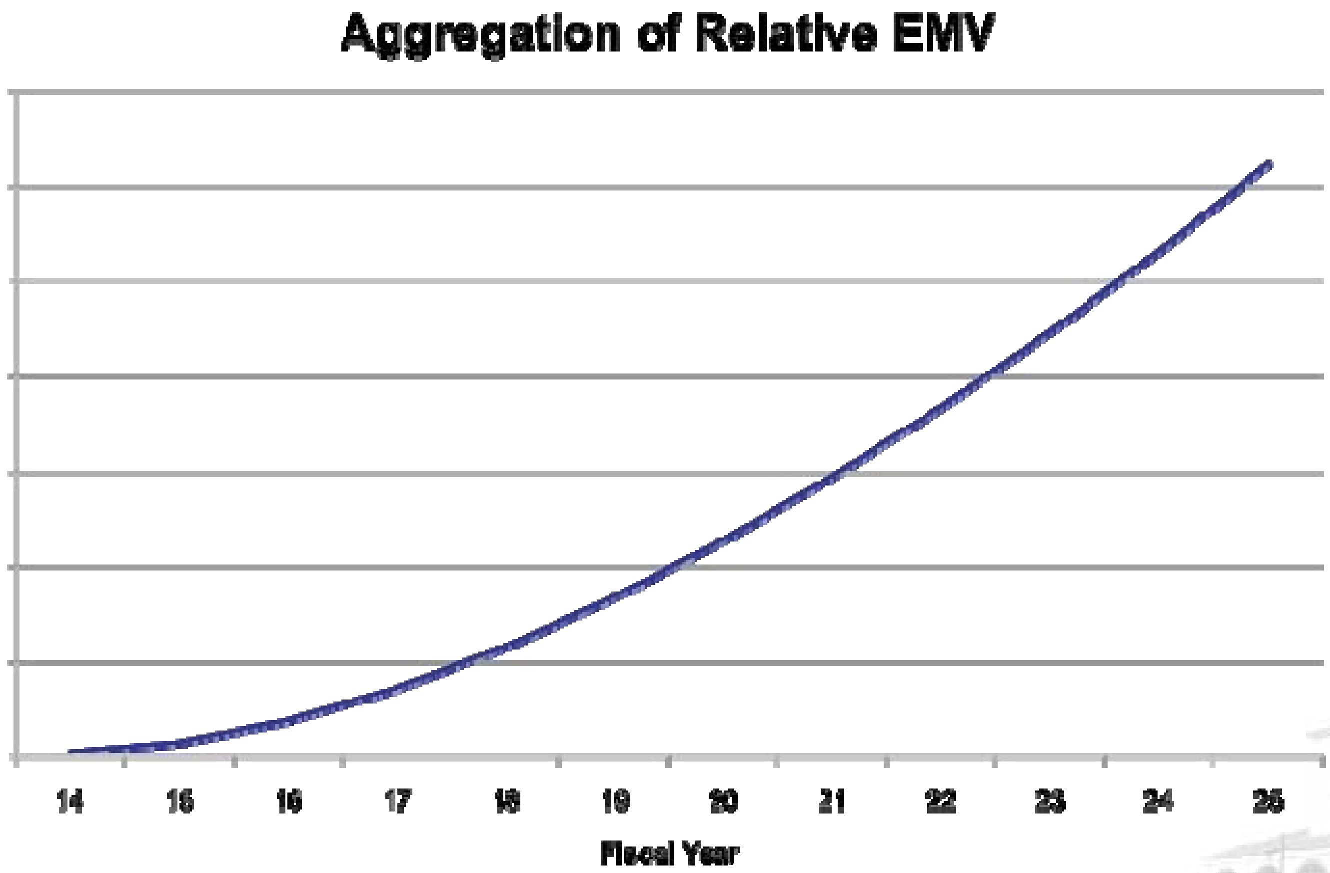
The problem addressed in this study deals with risk and value

- Value is realized through fielding of military capability for the war-fighter
- Risk is found in uncertainty
  - Cost uncertainty creates budget risk
  - Technology risk can lead to schedule and budget risk
- This study provided a pilot implementation of the Knowledge Value Added + Integrated Risk Management method to represent value and risk to assist the PM and sponsor in selecting the proper capability mix to field in a given ACB
- The problem space considered 23 capabilities to be implemented through changes to 32 software components across three scheduled ACBs (ACB 14, 16, and 18)
- Given the universe of desired capabilities, the problem is to select those providing the best value to the war-fighter for inclusion in a given ACB subject to budget constraints, risk and uncertainty of cost and timing

The study articulated a notional value of military value and used powerful financial and analytical tools

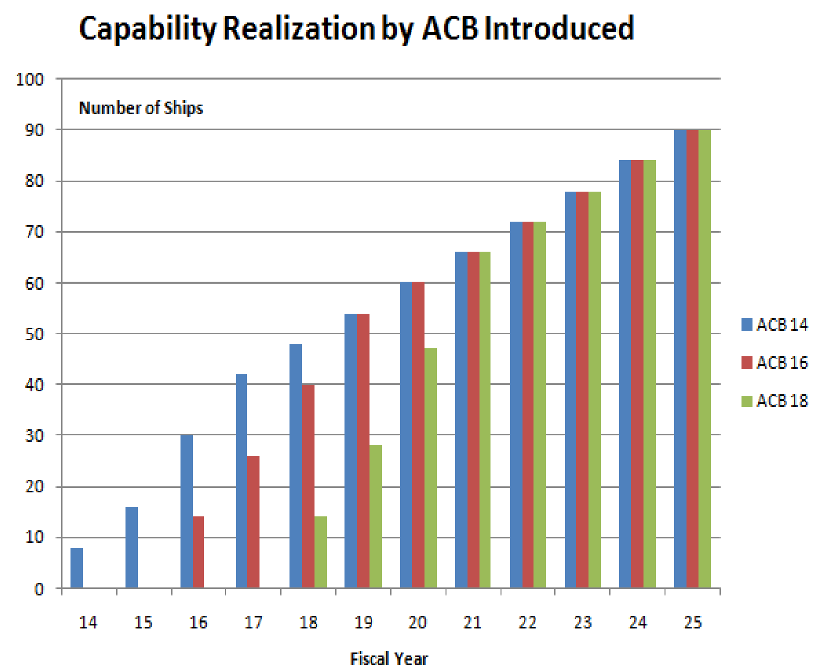
- Knowledge Value Added (KVA) provides ways of representing outputs (value) in common units
- Real Options provides tools to compare the value stream of various options in rigorous terms
- Integrated Risk Management considers uncertainties and represents risk in quantitative, clear and defensible terms

As ships enter the program and ACBs are executed, military value is additive



One advantage of the ACB process is the "catch-up" effect

- The ACB process helps manage risk by allowing the PM and sponsor to delay introduction of a particular capability until it is ready without waiting many years for the next cycle
- A delay until the next ACB is more acceptable because within five years the number of ships with the capability will be the same



The remainder of this presentation discusses the analysis and results

- Assumptions and constraints
- Measurement of military value (KVA)
- Application of Real Options and Integrated Risk Management (IRM) to the selection of capabilities

Assumptions and Constraints

- The study applied the following initial assumptions
  - The capabilities were independent of each other
  - Capabilities were implemented through changes to modules within the objective architecture
- Initial constraints assumed
  - A notional ***integration*** budget of $150 million per ACB
  - All uncertainty estimates for the initial model were based on cost volatility
- Future study will include
  - Effects of interdependencies (nested options), correlations, diversification
  - Schedule risk
  - Opportunity cost and penalty costs of abandonment

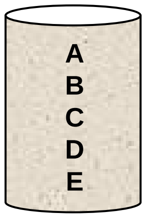
Measuring Value

- KVA **quantifies the value** of the knowledge used to produce common units of output
- Shows decision makers the **benefit and cost** of each program or project
- Measures how resources are allocated on the volatility of productivity (e.g., ROI)
- **Providing ROI volatility inputs to IRM**
- **Military value** in this study was postulated to be represented by capability provided to the warfighter measured in a variety of ways
  - Strategic importance as represented by OPNAV sponsor priorities
  - Technical value as represented by acquisition community priority
  - Functional complexity represented by Delivered Source Lines of Code (DSLOC)
  - Subject Matter Expert evaluation of complexity and mission criticality, aggregated from the component level

Integrated Risk Management Process

1 **List of projects and strategies to evaluate**

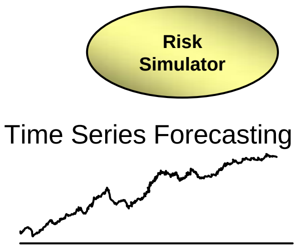
RISK IDENTIFICATION



Start with a list of projects or strategies to be evaluated… these projects have already been through qualitative screening

2 **Base case projections for each project**

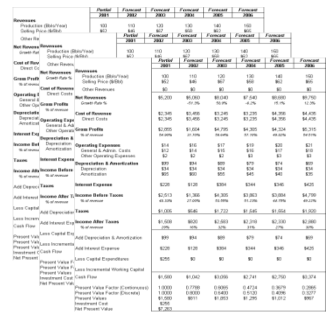
RISK PREDICTION



…with the assistance of time-series forecasting, future outcomes can be predicted...

3 **Develop static financial models**

RISK MODELING

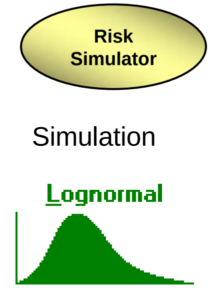


Traditional analysis stops here!

…the user generates a traditional series of static base case financial (discounted cash flow) models for each project…

4 **Dynamic Monte Carlo simulation**

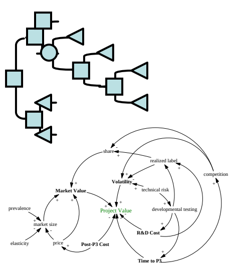
RISK ANALYSIS



…Monte Carlo simulation is added to the analysis and the financial model outputs become inputs into the real options analysis…

5 **Framing Real Options**

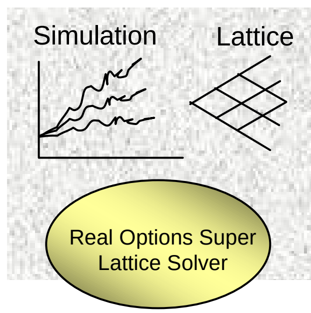
RISK MITIGATION



…the relevant projects are chosen for real options analysis and the project or portfolio real options are framed…

6 **Options analytics, simulation, optimization**

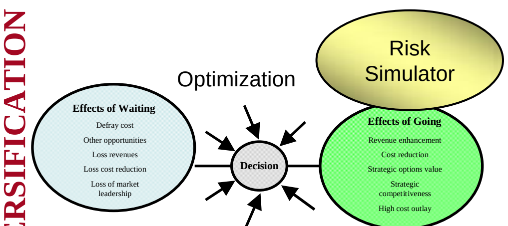
RISK HEDGING



…real options analytics are calculated through binomial lattices and closed-form partial-differential models with simulation…

7 **Portfolio optimization and asset allocation**

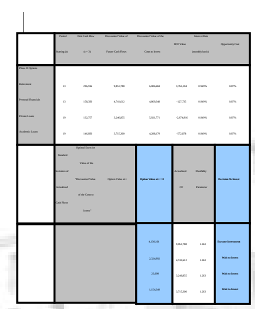
RISK DIVERSIFICATION



…stochastic optimization is the next optional step if multiple projects exist that require efficient asset allocation given some budgetary constraints… useful for strategic portfolio management…

8 **Reports presentation and update analysis**

RISK MANAGEMENT



…create reports, make decisions, and do it all again iteratively over time…

KVA+RO+IRM are a combination of method and toolset to assist the PM in decision making

- Knowledge Value Added (KVA) is a method that systematically expresses non-revenue activities in common units of output to quantify value
- Real Options (RO) provides a way to qualitatively and quantitatively evaluate the relative value of various courses of action under consideration
- Integrated Risk Management combines KVA and RO with a powerful toolset to assist the program manager in the decision process
- Treatment of parameters as distributions permits rigorous analysis in an uncertain world, where instead of single point estimates, we use ranges as inputs
- Monte Carlo risk simulation and process models permit consideration of all possible outcomes within a reasonable time period
- Disciplined processes yield defensible results that can be updated as more knowledge/ information is realized by the program
- Risk simulation, sensitivity analysis, and forecasting are automated (analyses are efficient, quick, consistent, replicable, defensible, and scalable)

The toolset and method provide a way for the PM to determine the relative merits of the various options available, to make informed choices based on value streams and risk, and then to articulate those choices to the sponsor and the acquisition chain of command.

Model input assumptions are entered on a data sheet

Common sizing inputs and using weights to obtain the expected military value

Capability	High	Mid	Low	SME Mean Value Added	Technical Priority	OPNAV Priority	DSLOC Complexity	Cost Simulation	Technical Priority H-L	OPNAV Priority H-	SMEVA and DSLOC Only EMV Score	All Weighted & Common Sized EMV Score	OPNAV & Technical Priority EMV Score	Objective Used	CV
Common Size Factor				1.00			0.10		2.00	2.00					
Weighting Scheme				35%			35%		15%	15%					
Capability 1				43.00	3	2	278	29.00	21	22	321.00	37.68	43.00	43.00	0.1834
Capability 2				28.00	2	1	541	126.00	22	23	569.00	42.24	45.00	45.00	0.0903
Capability 3				13.00	1	3	58	77.00	23	21	71.00	19.78	44.00	44.00	0.0719
Capability 4				40.33	5	4	635	21.00	19	20	675.33	48.04	39.00	39.00	0.0576
Capability 5				17.67	7	7	134	15.00	17	17	151.67	21.07	34.00	34.00	0.0407
Capability 6				35.67	4	6	392	27.00	20	18	427.67	37.60	38.00	38.00	0.1568
Capability 7				50.67	6	5	549	17.00	18	19	599.67	48.05	37.00	37.00	0.0481
Capability 8				47.67	10	11	675	77.00	14	13	722.67	48.41	27.00	27.00	0.0689
Capability 9				19.00	8	8	109	16.00	16	16	128.00	20.07	32.00	32.00	0.0382
Capability 10				33.67	11	9	189	10.00	13	15	222.67	26.80	28.00	28.00	0.0603
Capability 11				20.00	9	10	88	3.00	15	14	108.00	18.78	29.00	29.00	0.0707
Capability 12				27.67	14	12	159	21.00	10	12	186.67	21.85	22.00	22.00	0.1137
Capability 13				27.67	12	13	159	11.00	12	11	186.67	22.15	23.00	23.00	0.0408
Capability 14				44.67	13	14	523	27.00	11	10	567.67	40.24	21.00	21.00	0.0956
Capability 15				17.67	20	15	134	10.00	4	9	151.67	14.77	13.00	13.00	0.0603
Capability 16				17.67	21	16	134	5.00	3	8	151.67	14.17	11.00	11.00	0.0816
Capability 17				34.33	19	17	328	9.00	5	7	362.33	27.10	12.00	12.00	0.0454
Capability 18				17.67	22	18	134	6.00	2	6	151.67	13.27	8.00	8.00	0.0372
Capability 19				14.00	23	19	81	18.00	1	5	95.00	9.54	6.00	6.00	0.0340
Capability 20				17.67	15	20	134	14.00	9	4	151.67	14.77	13.00	13.00	0.0164
Capability 21				22.67	18	21	144	18.00	6	3	166.67	15.67	9.00	9.00	0.0454
Capability 22				11.67	16	22	180	78.00	8	2	191.67	13.38	10.00	10.00	0.0468
Capability 23				10.00	17	23	95	10.00	7	1	105.00	9.23	8.00	8.00	0.0603

Actual Capabilities Redacted

Cost Data Redacted

Starting with 23 capabilities (more to be added later when there is sufficient data)

High, most likely, low cost estimates for running thousands of simulation trials

Technical and OPNAV priorities

DSLOC provides a measure of complexity

Intermediate computations: risk-simulation assumption, readjusted priorities, expected military score and cost-based risk coefficients

Running the model provides recommended selections

ACB 14 sample results with $150M budget constraint

Expected Military Value: SME Mean Value Added, DSLOC Complexity, Common Sized, Weighted OPNAV/Technical Priorities

Selection of EMV calculation method

Reset

Actual Capabilities Redacted

Cost Data Redacted

Capability	EMV	Cost	Risk $	Risk %	Selection
Capability 1	37.68		$6.91	18.34%	0.0000
Capability 2	42.24		$3.81	9.03%	0.0000
Capability 3	19.78		$1.42	7.19%	0.0000
Capability 4	48.04		$2.77	5.76%	1.0000
Capability 5	21.07		$0.86	4.07%	1.0000
Capability 6	37.60		$5.90	15.68%	0.0000
Capability 7	48.05		$2.31	4.81%	1.0000
Capability 8	48.41		$3.34	6.89%	0.0000
Capability 9	20.07		$0.77	3.82%	1.0000
Capability 10	26.80		$1.62	6.03%	1.0000
Capability 11	18.78		$1.33	7.07%	1.0000
Capability 12	21.85		$2.48	11.37%	0.0000
Capability 13	22.15		$0.90	4.08%	1.0000
Capability 14	40.24		$3.85	9.56%	1.0000
Capability 15	14.77		$0.89	6.03%	1.0000
Capability 16	14.17		$1.16	8.16%	1.0000
Capability 17	27.10		$1.23	4.54%	1.0000
Capability 18	13.27		$0.49	3.72%	1.0000
Capability 19	9.54		$0.32	3.40%	0.0000
Capability 20	14.77		$0.24	1.64%	0.0000
Capability 21	15.67		$0.71	4.54%	0.0000
Capability 22	13.38		$0.63	4.68%	0.0000
Capability 23	9.23		$0.56	6.03%	0.0000
Total	314.51	$150.00	$6.18		
Constraints:	MAX	$150.00			

Max EMV

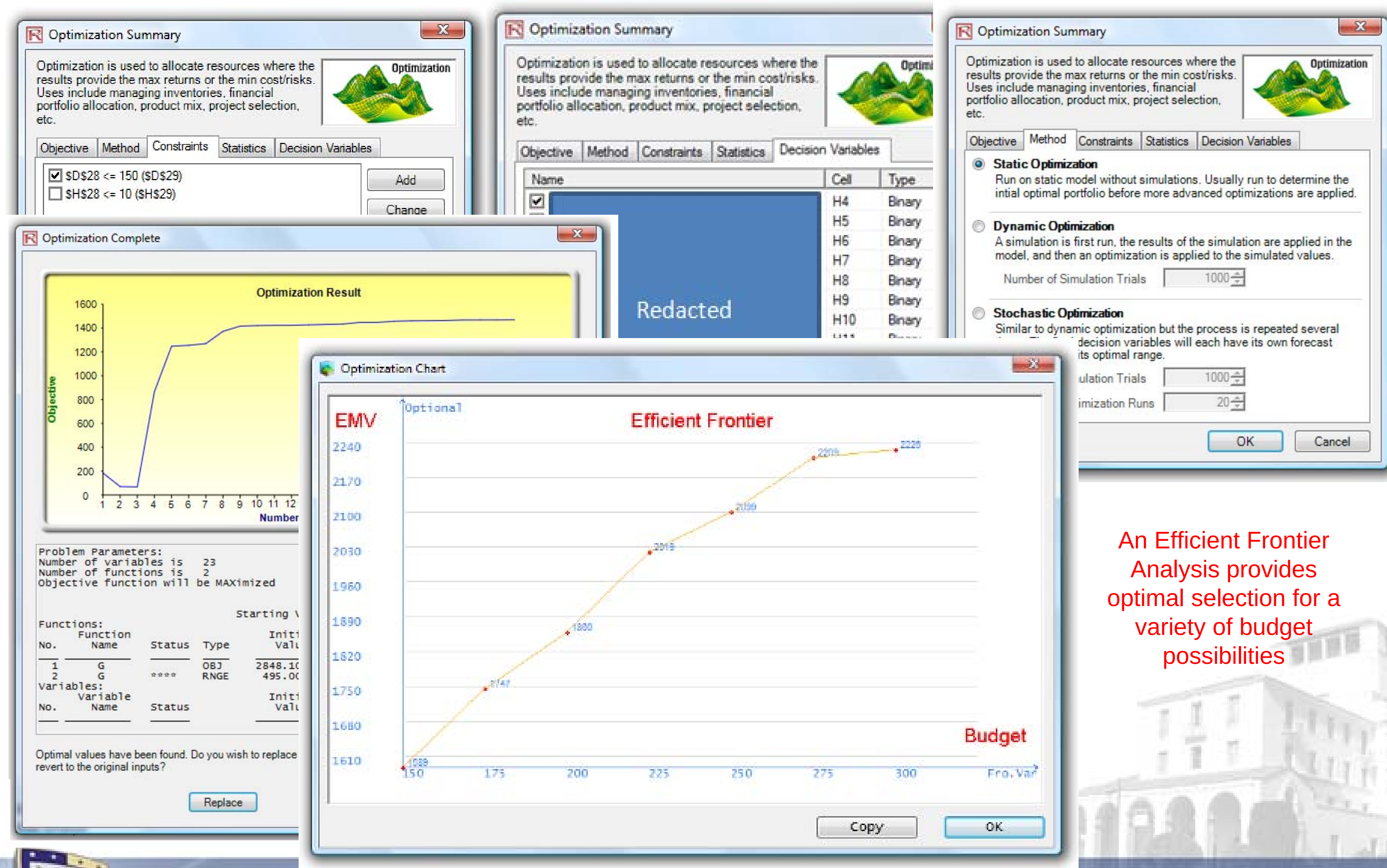
Go or No-Go decisions in the portfolio selection

Benefits (EMV), Cost, Risk are considered

Constraints can be set (budget, capability count, FTE, priorities, etc)

Starting with 23 capabilities (more to be added later when there is sufficient data)

Portfolio optimization analysis gives a set of solutions



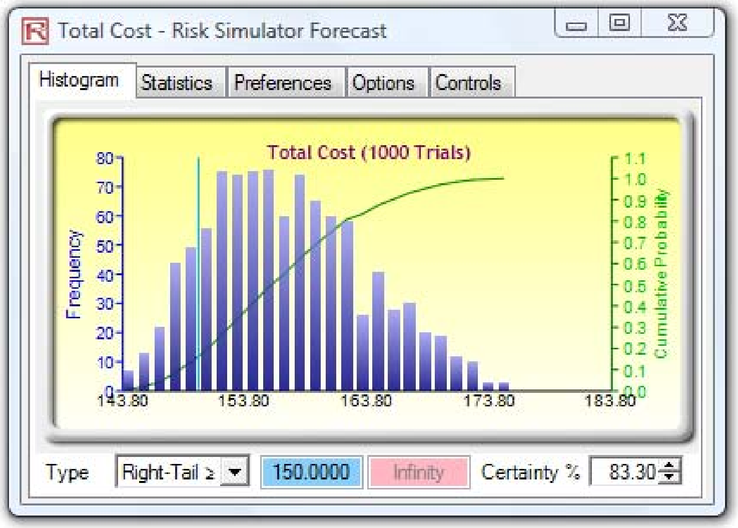
An Efficient Frontier Analysis provides optimal selection for a variety of budget possibilities

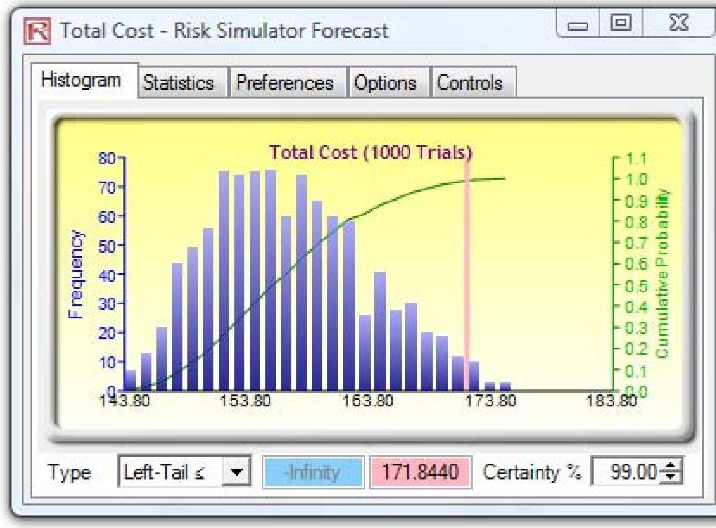
Risk simulation of cost provides the decision maker with additional data

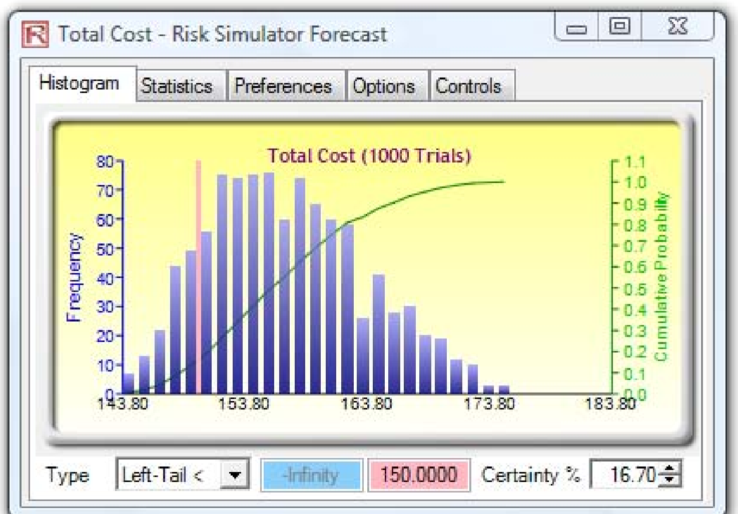
Risk analysis and 100,000 simulation trials on cost estimations…

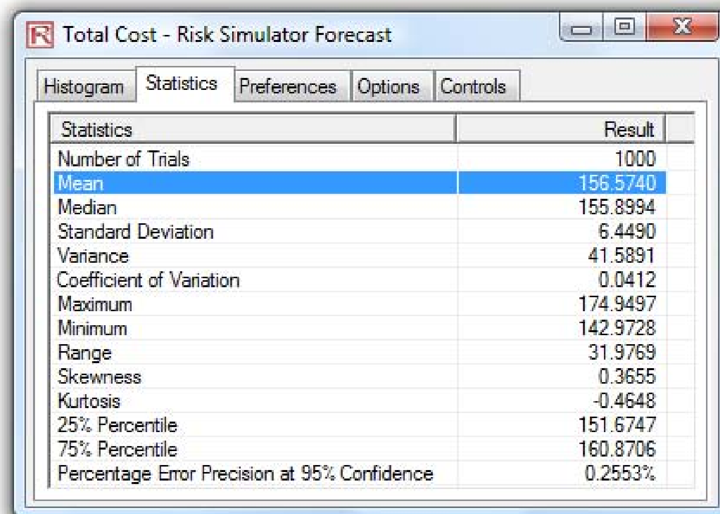
We can determine the probability that ACB-X will exceed the $150M budget, determine what $171M will yield a 99% certainty of sufficient budget to cover all costs

We also looked at the optimal portfolio given a 90% probability that $150M will be enough









Statistics	Result
Number of Trials	1000
Mean	156.5740
Median	155.8994
Standard Deviation	6.4490
Variance	41.5891
Coefficient of Variation	0.0412
Maximum	174.9497
Minimum	142.9728
Range	31.9769
Skewness	0.3655
Kurtosis	-0.4648
25% Percentile	151.6747
75% Percentile	160.8706
Percentage Error Precision at 95% Confidence	0.2553%

*Screen shots from Risk Simulator software

Optimized portfolios are time-sequenced and risks are quantified

Actual Capabilities Redacted

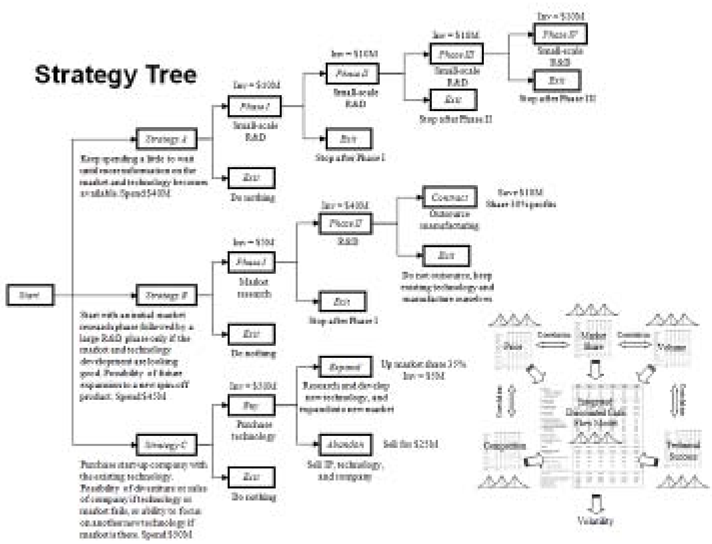
Capability	Optimal on Budget	Optimal Cost-Risk	Must-Have	Cost-Risk
Capability 1	ACB16	ACB16	ACB16	ACB18
Capability 2	ACB18	Later	ACB14	ACB14
Capability 3	Later	Later	Later	Later
Capability 4	ACB14	ACB14	ACB16	ACB16
Capability 5	ACB16	ACB14	ACB16	ACB16
Capability 6	ACB14	ACB16	ACB18	ACB18
Capability 7	ACB14	ACB14	ACB16	ACB16
Capability 8	Later	ACB18	ACB18	Later
Capability 9	ACB16	ACB14	ACB18	ACB16
Capability 10	ACB14	ACB14	ACB16	ACB16
Capability 11	ACB14	ACB14	ACB14	ACB14
Capability 12	ACB16	ACB16	ACB18	ACB18
Capability 13	ACB14	ACB14	ACB16	ACB16
Capability 14	ACB14	ACB14	ACB16	ACB16
Capability 15	ACB14	ACB16	ACB16	ACB18
Capability 16	ACB14	ACB14	ACB14	ACB16
Capability 17	ACB14	ACB14	ACB14	ACB16
Capability 18	ACB14	ACB14	ACB14	ACB16
Capability 19	ACB16	ACB18	Later	Later
Capability 20	ACB16	ACB16	Later	ACB18
Capability 21	ACB16	ACB16	Later	ACB18
Capability 22	Later	Later	Later	Later
Capability 23	ACB16	ACB16	ACB16	ACB18

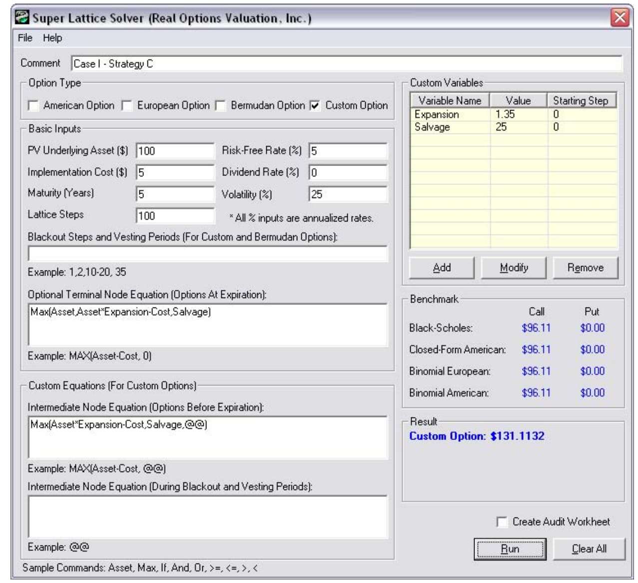
ACB 14 + ACB 16 + ACB 18

*rounded to the nearest 0.1

	Optimal on Budget	Optimal Cost-Risk	Must-Have	Cost-Risk
Total Capabilities ACB14	11	11	5	2
Total Capabilities ACB16	8	7	9	10
Total Capabilities ACB18	1	2	4	7
EMV ACB14	310.98	299.74	115.56	61.02
EMV ACB16	149.87	151.58	268.03	280.96
EMV ACB18	42.24	57.94	127.93	151.58
Total Cost ACB14	$146.00	$139.00	$149.00	$129.00
Total Cost ACB16	$141.00	$129.00	$150.00	$137.00
Total Cost ACB18	$126.00	$95.00	$141.00	$129.00
Total Spent on ACB14-18	$413.00	$363.00	$440.00	$395.00
Probability of Under Budget ACB14	29.70%	97.90%	41.50%	90.80%
Probability of Under Budget ACB16	72.23%	90.90%	16.25%	99.90%
Probability of Under Budget ACB18	94.80%	99.90%	72.90%	90.90%
ACB14 Median 50th Percentile on Budget	$153.20	$142.90	$152.60	$132.30
ACB14 Median 85th Percentile on Budget	$160.22	$146.60	$166.60	$146.30
ACB14 Median 95th Percentile on Budget	$164.30	$148.70	$173.90	$153.50
ACB16 Median 50th Percentile on Budget	$145.40	$137.90	$156.50	$139.50
ACB16 Median 85th Percentile on Budget	$153.50	$147.30	$164.80	$143.30
ACB16 Median 95th Percentile on Budget	$157.80	$152.70	$169.20	$145.30
ACB18 Median 50th Percentile on Budget	$128.90	$95.30	$145.10	$137.90
ACB18 Median 85th Percentile on Budget	$142.90	$101.30	$153.50	$147.30
ACB18 Median 95th Percentile on Budget	$150.20	$104.30	$158.40	$152.70

More complex options and constraints can be accommodated in the analyses

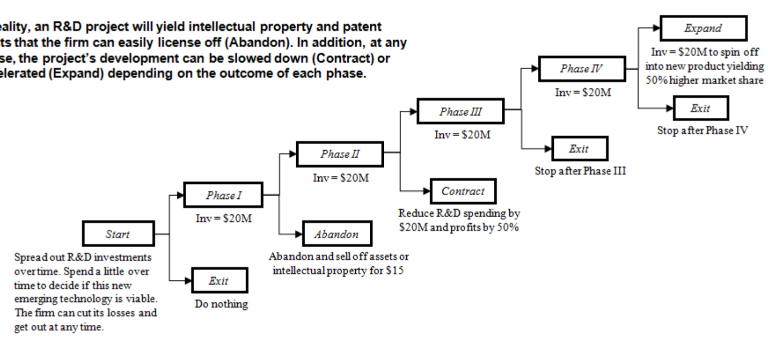




Inclusion of Analysis of Alternatives or Courses of Action using strategic real options analysis of various implementation pathways, suitable for nested and path dependent options (some components and capabilities are interdependent)

Strategy Tree
(Complex Multi-Stage Development)

In reality, an R&D project will yield intellectual property and patent rights that the firm can easily license off (Abandon). In addition, at any phase, the project's development can be slowed down (Contract) or accelerated (Expand) depending on the outcome of each phase.



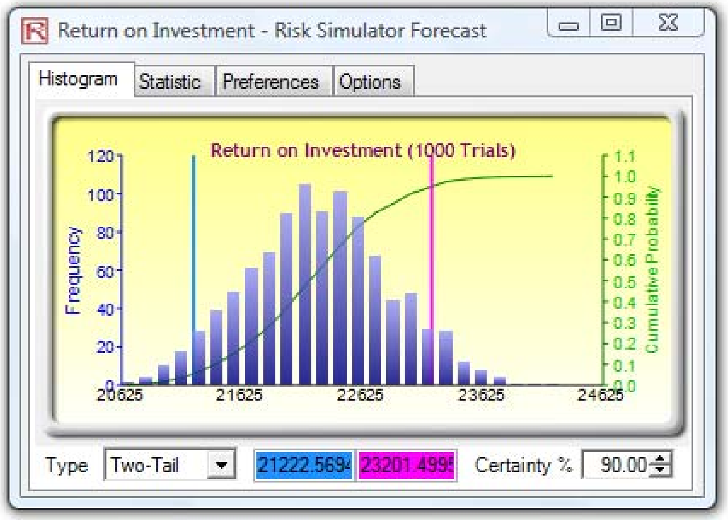
- Risk can be mitigated or planned for though
  - Budgeting to the amount that the simulator reveals is necessary to provide a given level of risk
  - Improving cost estimate quality and reducing volatility
  - Up-front action to change the cost equation
    - Contractual limits on cost through use of fixed price or other contract vehicles to shift risk with the vendor
    - Incentives to the contractor that reward for success and penalize for failure to meet cost targets
- Capability selection can also be accomplished by applying risk constraints during the optimization

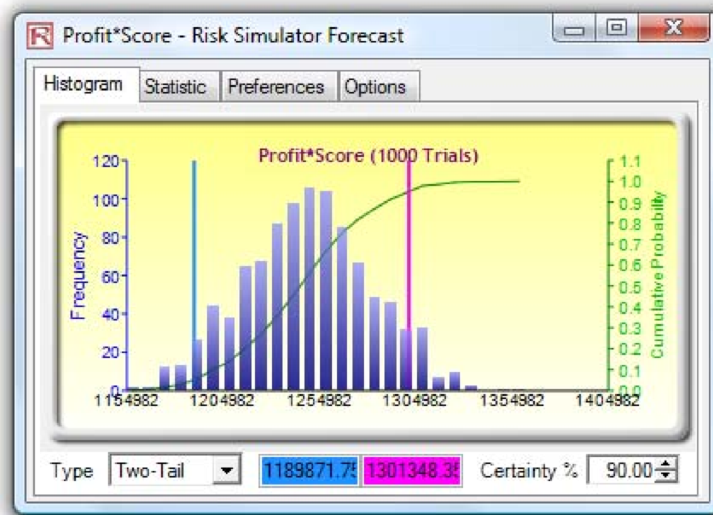
Going forward

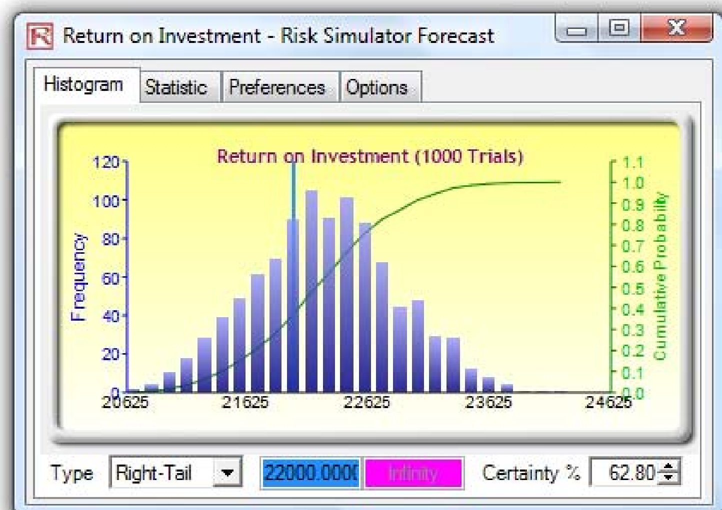
- More complex analyses to determine which optimization portfolio to choose
  - nested and mutually exclusive options among and between various capabilities
  - expansion options of a base capability into additional capabilities
- Strategic real options approach to generate different implementation pathways
  - provide strategic option trees
  - identify best decision strategic option pathway

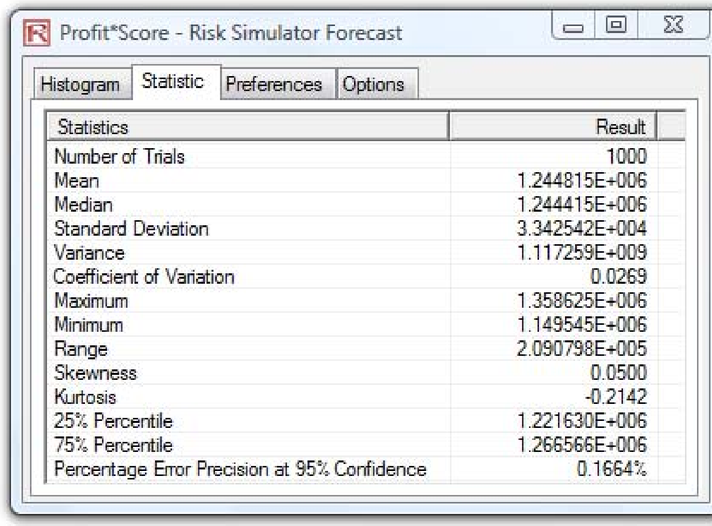
Back up slides

Risk Simulation (Risk Management) shows the range of likely outcomes









Statistics	Result
Number of Trials	1000
Mean	1.244815E+006
Median	1.244415E+006
Standard Deviation	3.342542E+004
Variance	1.117259E+009
Coefficient of Variation	0.0269
Maximum	1.358625E+006
Minimum	1.149545E+006
Range	2.090798E+005
Skewness	0.0500
Kurtosis	-0.2142
25% Percentile	1.221630E+006
75% Percentile	1.266566E+006
Percentage Error Precision at 95% Confidence	0.1664%

Risk Analytics (sensitivity, tornado, fitting, and many other analytical tools) provide depth of understanding