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Empirical Cost Modeling

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Overview

- Goal: Develop alternative or additional ship cost modeling methodologies
  - develop a comprehensive cost modeling strategy and approach
  - can be used to empirically predict, forecast, and model ship costs
  - not based on weight alone but complements weight-based methods
  - helps triangulate actual cost that may be stochastic
- Used the Arleigh Burke Class Guided Missile Destroyer DDG 51 Flight I, Flight II, Flight IIA, and Flight III as a basis for the cost and schedule assumptions
  - information and data were obtained via publicly available sources and were collected, collated, and used in an integrated risk-based cost and schedule modeling methodology (using high-level publicly available data; need more specific data to ensure accuracy)
  - results will be used to develop recommendations and develop a cost modeling toolset on how to implement ship cost forecasts
- Methodology provides a roadmap for modeling costs for any ship to be developed and built by the U.S. Navy
  - should result in improved cost savings without sacrificing effectiveness
- Related to Flexible Ships project (Thursday presentation) where we identify, model and justify the higher costs to prebuild growth margins and flexibility for implementing future unknown requirements to face future unknown threats

Summary Points

- Current approaches are usually weight-based methods although other approaches are considered or used
- Weight-based is efficient and simpler to model and approximate but in most cases inadequate as a stand-alone approach (e.g., buying apples at the store)
- Weight alone does not account for complexity (e.g., density)
- Modularity and flexibility may not be linked to weight alone – modular and flexible ships as a case example
- LCS mission bays (steel is heavy and expensive but air is free) – cost alone may not imply value
- Bottom-up Process Cost Model approaches may also be important as these account for efficiency and complexity vs. Top-down Econometric Models
- Total Ownership Cost (TOC), Lifecycle Cost, Acquisition Cost, Ship-Alt Cost are important in justifying strategic options and margins for flexible ships
- Cost Risk and Schedule Risk are the two related and major uncertainties
- Analyzed multiple approaches: ARIMA, Econometric Modeling, Fuzzy Logic, GARCH, Genetic Algorithms, Monte Carlo Risk Simulations, Multivariate Nonlinear Regression, Process Models…

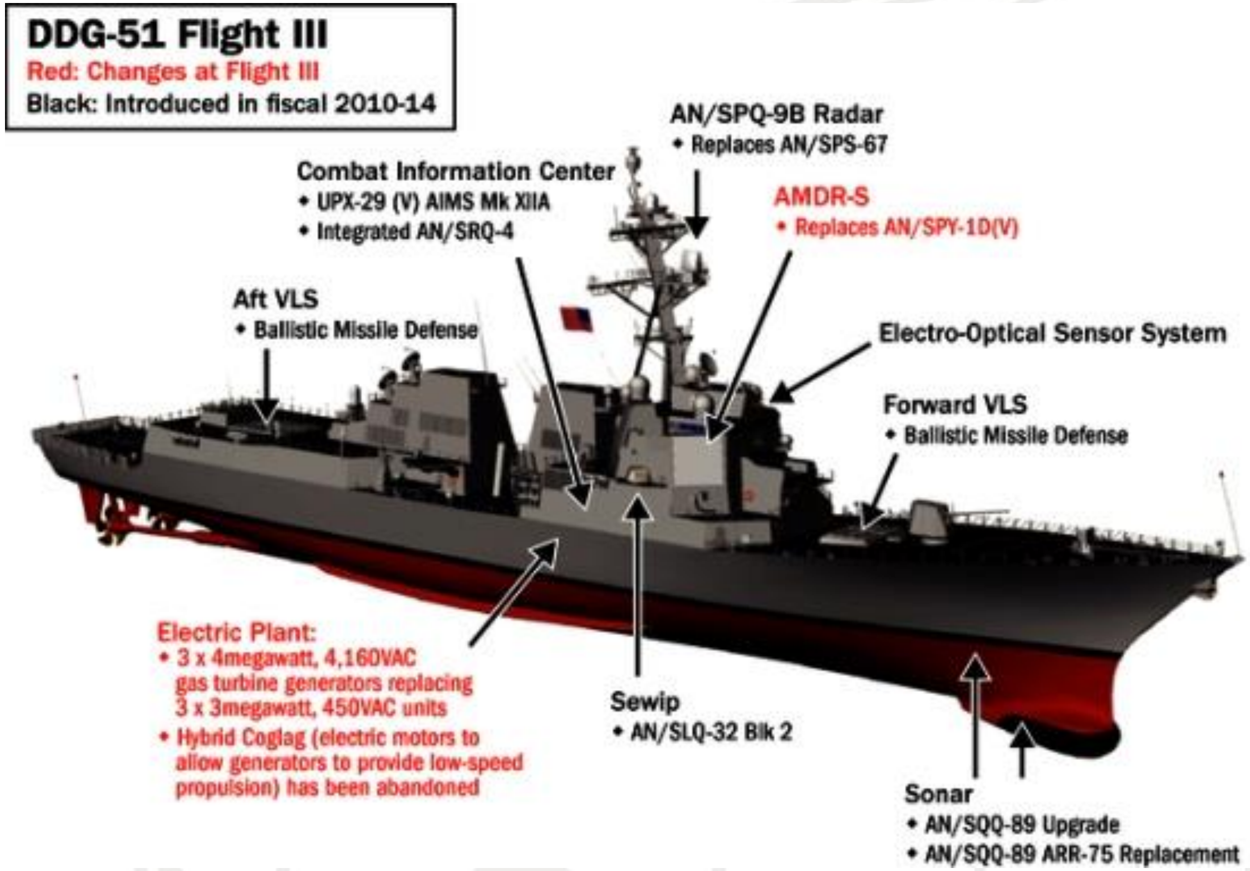
Overview of U.S. Navy Ships (DDG 51 Destroyer Class)

Cost Modeling

The Navy Ship Models Reviewed: **Arleigh Burke Class Guided Missile Destroyer DDG 51 Flight I, Flight II, Flight IIA, Flight III**, and also the Joint High Speed Vessel (JHSV), CG 47 Ticonderoga, DDG 1000 Zumwalt, LPD 17 San Antonio Class, LHA 6 America Class, and Nimitz Class Aircraft Carrier (CVN 68), among others warship models.

In the cost analysis models, we will consider the full build of the ship, with its accoutrements such as weapons systems, electrical systems, radar and electronic warfare systems, communication and navigation systems, aircraft, and other extra add-ons.

Cost-Schedule estimation follows a ***bottom-up*** approach, and the Multivariate Analysis (parametric) follows a ***top-down*** approach.



Department of Defense (DoD) Budget Data (DDG 51 Destroyer)

Information and data were obtained via publicly available sources and were collected, collated, and used in an integrated cost modeling methodology. Due to lack of proprietary data, we used publicly sourced information and applied subject matter expert opinions. The objective of this study is to develop a comprehensive cost modeling strategy and approach, and Notional Data were used to perform Rough Order Magnitude (ROM) estimates.

DoD Spending, Procurement and RDT&E: FY 2012/13/14 + Budget for FYs 2015 + 2016 Go to Top

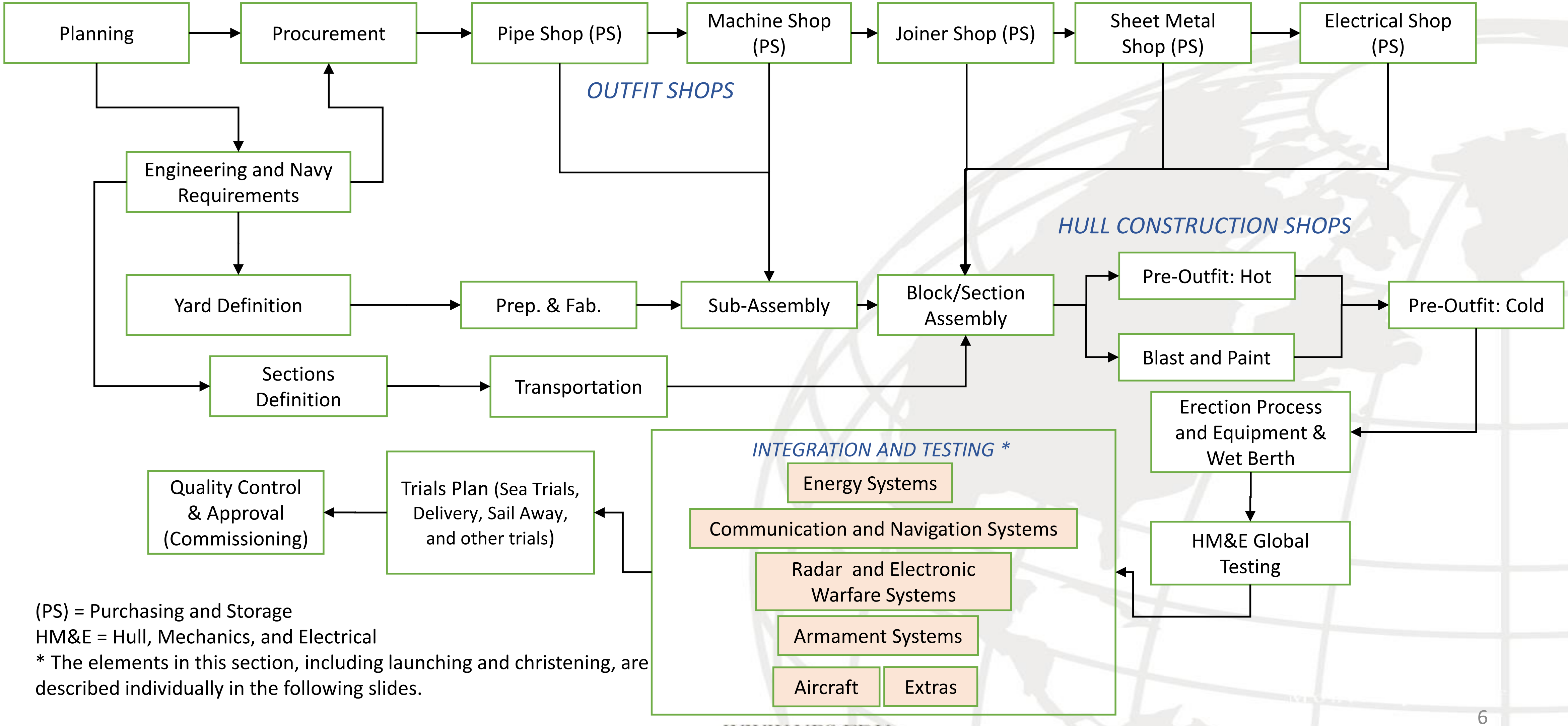
DDG 51 AEGIS Destroyer		ACTUAL FY2012 Total QTY	ACTUAL FY2012 Total Million $	ACTUAL FY2013 Total QTY	ACTUAL FY2013 Total Million $	ACTUAL FY2014 Total QTY	ACTUAL FY2014 Total Million $	PRELIMINARY FY2015 Total QTY	PRELIMINARY FY2015 Total Million $	REQUESTED FY2016 Total QTY	REQUESTED FY2016 Total Million $
Procurement											
Shipbuilding & Conversion	NAVY	1	2,081.43	3	4,497.01	1	1,985.12	2	2,795.95	2	3,149.70
Ship Modifications	NAVY		126.37		407.71		285.99		324.22		364.16
Completion Costs	NAVY		-		-		100.00		129.14		-
Outfitting & Post Delivery	NAVY		49.10		7.30		1.30		6.50		62.10
Total Procurement		1	2,256.91	3	4,912.02	1	2,372.41	2	3,255.81	2	3,575.96
RDT&E (Hybrid Electric Drive)	NAVY		-		-		-		7.95		4.22
Total RDT&E			-		-		-		7.95		4.22
Total Program Spending		**1**	**2,256.91**	**3**	**4,912.02**	**1**	**2,372.41**	**2**	**3,263.76**	**2**	**3,580.18**

FY2017-FY2020 Budget Data in PDF files below table →→→

Download Official U.S. Department of Defense (DoD) Budget Data:

Shipbuilding & Conversion | DDG-51 AEGIS Destroyer

Process Flow: Planning, Design, Construction, Integration, Trials & Commissioning



(PS) = Purchasing and Storage
HM&E = Hull, Mechanics, and Electrical
* The elements in this section, including launching and christening, are described individually in the following slides.

Applied Analytics and Risk Analysis
*(Bottom-Up Cost & Schedule Estimations)**

*Based on publicly available cost data

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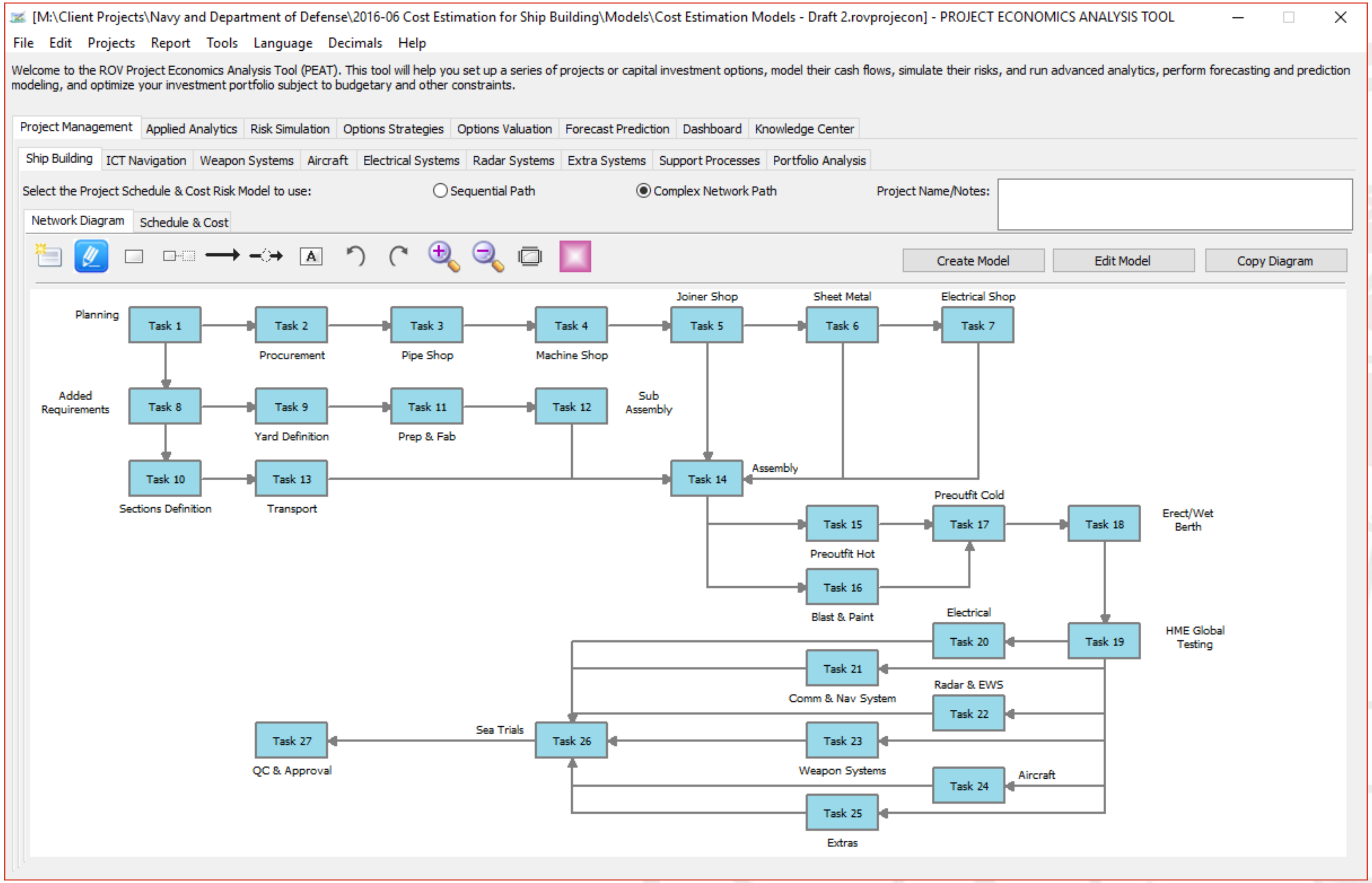
WBS and Global Network Diagram of Warship Building

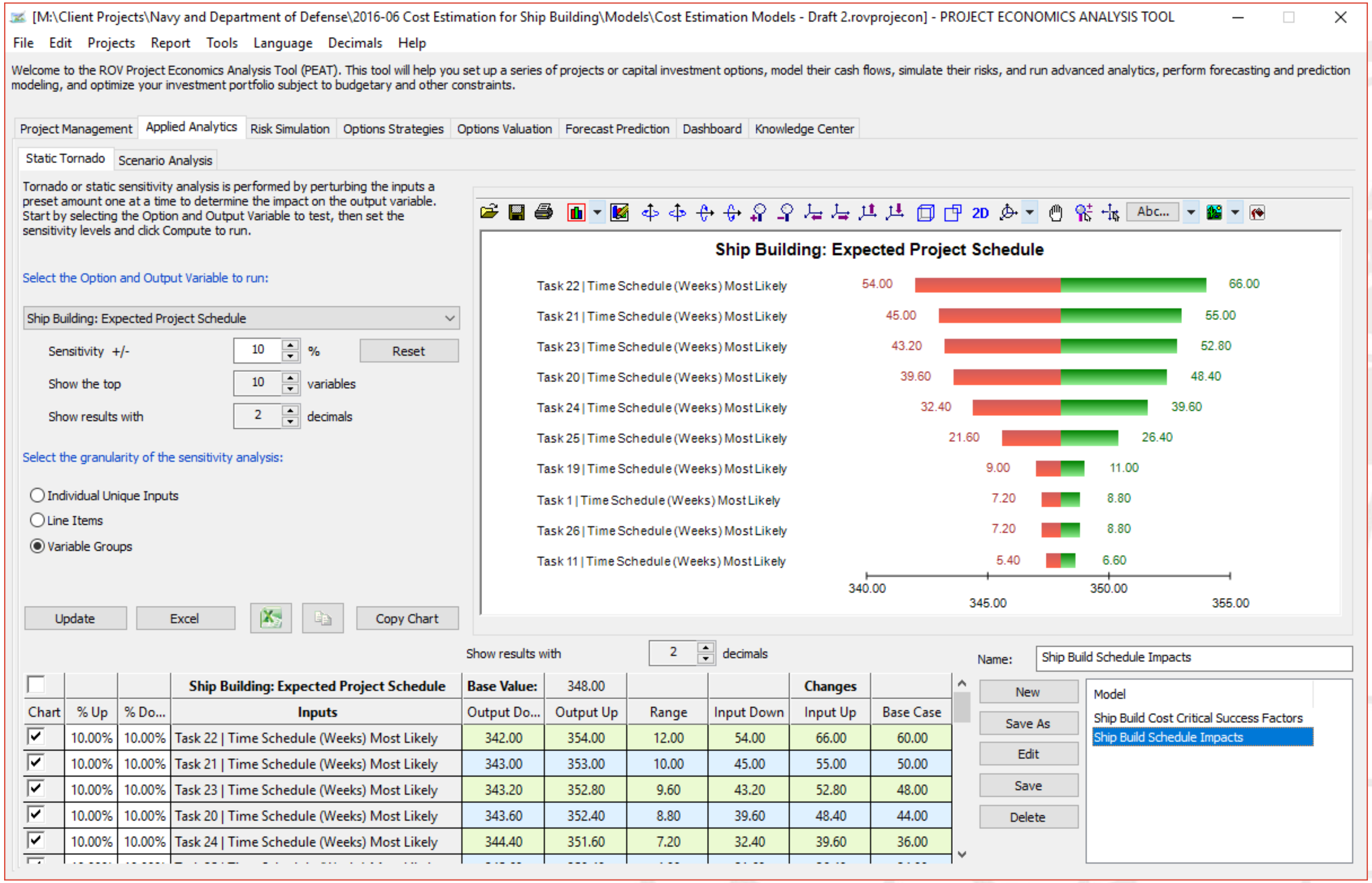


Cost Modeling (Research and Data Analysis)

Cost information on Navigation, Weapons, and Aircraft were obtained and is illustrated below:

Category	Items	Quantity	Min Unit Cost	Aveg Unit Cost	Max Unit Cost	Total Cost ($M)
Navigational Equipment	AN/WSN-5 Inertial Navigation System; AN/WRN-6 ; ANISRN-25 (V); MK 4	1	8	14	20	14.00
	MK 6 MOD 4D Digital Dead Reckoning Tracer					
	AN/URN-25 TACAN; AN/SPS-64 (V) 9 I Band Radar					
	Navy Standard No. 3 Magnetic Compass;					
	Total Navigation system	1	15.84	19.8	23.76	19.80
	Chronometer Size 85; Flux Compass					
Total		***2***	***23.84***	***33.80***	***43.76***	***33.80***
Weapons						
	RIM-66 Standard Missile SM-2MR; RIM-67/RIM-156 Standard Missile SM-2ER					
	RIM-161 Standard Missile SM-3	74	3	3.24	10.07	239.76
	Vertical Launch ASROC (VLA) missiles;					
	MK 41 Vertical Missile Launch Systems (VLS)	2	38.2	110.1	182	220.20
	BGM-109 Tomahawk	1	0.4552	0.569	0.6828	0.57
	MK-46 torpedoes (from two triple tube mounts);	6				
	Close In Weapon System (CIWS),	1	3.04	3.8	4.56	3.80
	Mk-45 (Mod.1/2) 5”/54					
	RIM Evolved Sea Sparrow Missile (ESSM)	1	0.84	0.905	0.97	0.91
	MK 38 self--defense guns					
	Land-Attack Guns					
	Other type of Guided Missiles (Guided shell)	10	0.025	0.0375	0.05	0.38
	Other type of defined Guns and Torpedoes, missiles, being part of the ship's	1	641.40344	796.77	1296.242	796.77
Total		***96***	***686.96***	***915.42***	***1494.57***	***1262.38***
Aircraft	MH-60 B/R Seahawk LAMPS III helicopters with Penguin/ Hellfire missiles	2	27.693	30.77	60	61.54
	MK 46/MK 50 torpedoes					

Expected Project Schedule (Shipbuilding)

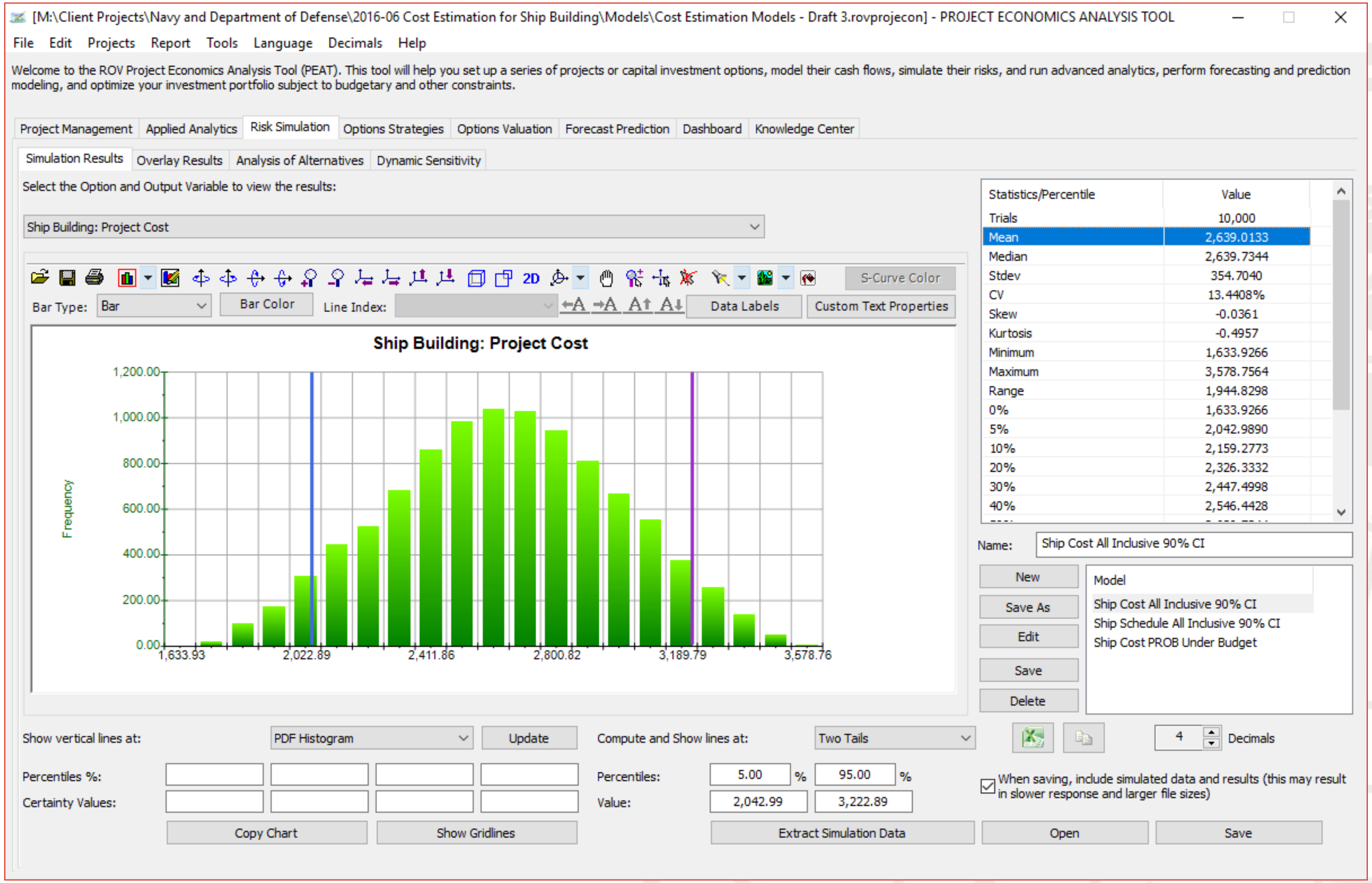


Risk Simulation with the U.S Air Force Cost Analysis Handbook

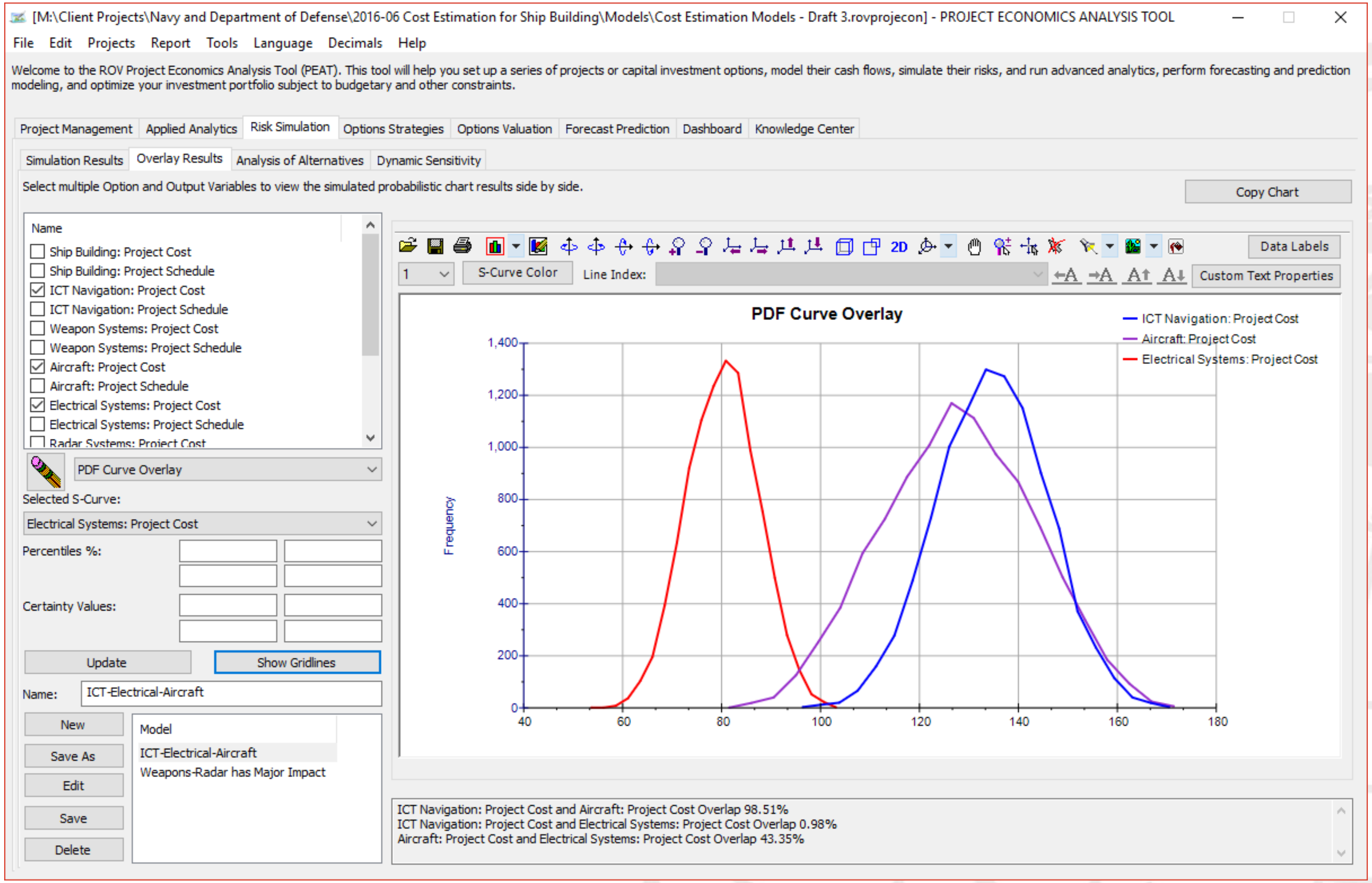
U.S. Air Force Cost Analysis Handbook (AFCAH)

						Fitted Distributions		
Distribution	PEI	Probability	15%	Mode	85%	Min	Likely	Max
Triangular Low Left	Mode	1.0 (75%)	0.695	0.878	1.041	0.482	0.878	1.247
Triangular Low	Mode	1.0 (50%)	0.834	1	1.166	0.633	1.000	1.367
Triangular Low Right	Mode	1.0 (25%)	0.959	1.122	1.305	0.753	1.122	1.518
Triangular Medium Left	Mode	1.0 (75%)	0.492	0.796	1.069	0.137	0.796	1.412
Triangular Medium	Mode	1.0 (50%)	0.723	1	1.277	0.388	1.000	1.612
Triangular Medium Right	Mode	1.0 (25%)	0.931	1.204	1.508	0.588	1.204	1.863
Triangular High Left	Mode	1.0 (75%)	0.347	0.754	1.103	0.000	0.754	1.550
Triangular High	Mode	1.0 (50%)	0.612	1	1.388	0.142	1.000	1.858
Triangular High Right	Mode	1.0 (25%)	0.903	1.236	1.711	0.442	1.236	2.225
Triangular EHigh Left	Mode	1.0 (75%)	0.3	0.745	1.15	0.000	0.745	1.657
Triangular EHigh	Mode	1.0 (50%)	0.509	1.004	1.5	0.000	1.004	2.100
Triangular EHigh Right	Mode	1.0 (25%)	0.876	1.367	1.914	0.258	1.367	2.553

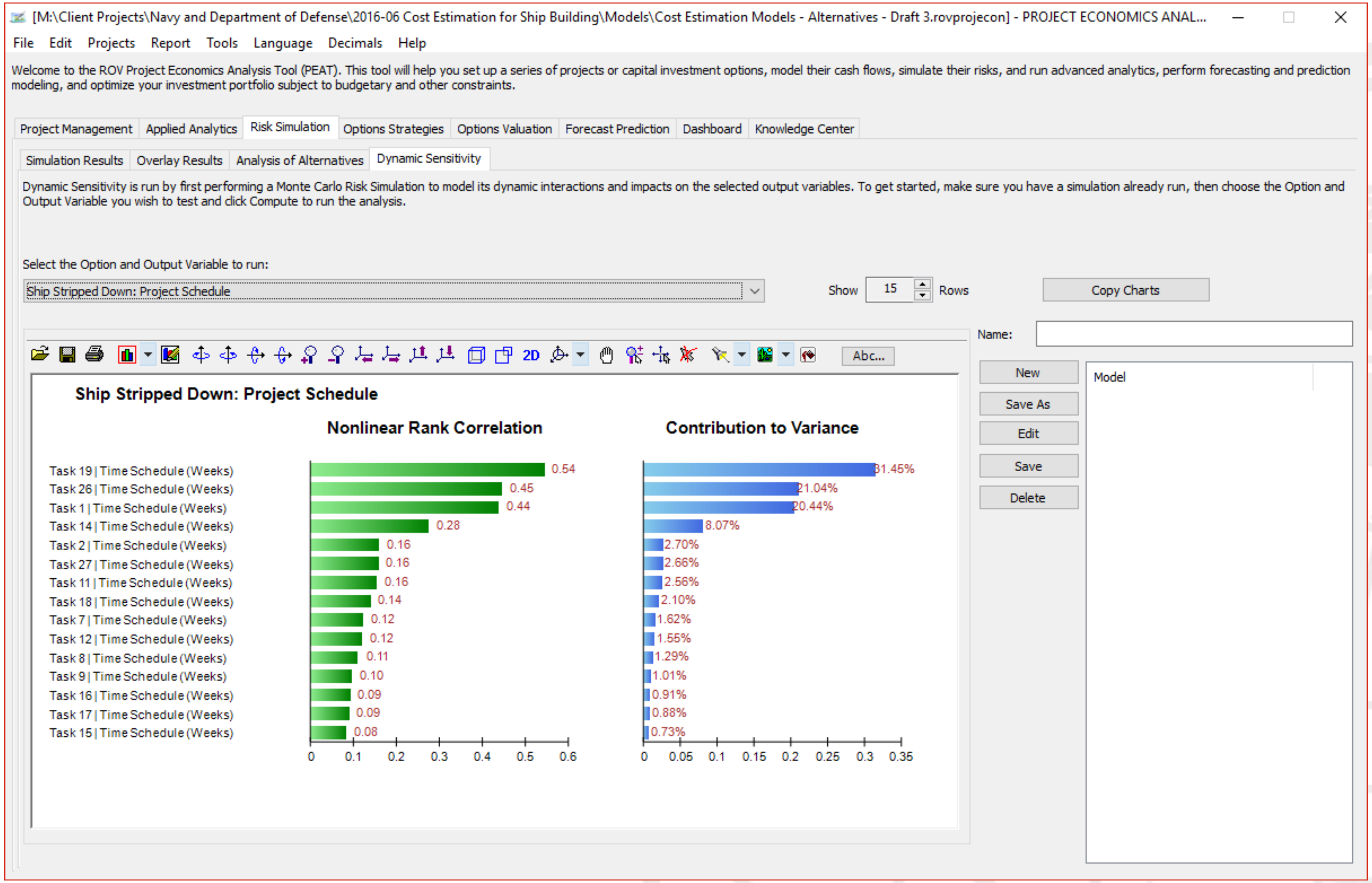
Expected Project Cost (Risk Profile)



Project Cost by Sections (Overlays and Stochastic Dominance)



Project Schedule (Sensitivity Analysis)



Econometric Analysis (Top-Down Cost Estimations)

Multivariate Analysis (Warship Prices)

ID	Navy Ship	Unit Cost ($M)	Displacement (Tons)	Speed (KMH)	Length (M)	Crew	Year	Value	Q
1	DDG 51	2133	9648	56	155.3	276	2012	2,133	1
2	DDG 51	1553	9648	56	155.3	276	2012	3,106	2
3	DDG 51	1884	9648	56	155.3	276	2012	1,884	1
4	DDG 51	1423	9648	56	155.3	276	2013	4,269	3
5	DDG 51	2372	9648	56	155.3	276	2014	2372	1
6	DDG 51	1615	9648	56	155.3	276	2015	1,615	1
7	DDG 51	1330.5	9648	56	155.3	276	2016	2,661	2
8	DDG 1000	3554	15730	56	185.9	148	2007	3554	1
9	DDG 1000	3010	15730	56	185.9	148	2008	3010	1
10	Joint High Speed Vessel (JHSV)	185	2397	80	103	41	2010	185	1
11	Joint High Speed Vessel (JHSV)	184	2397	80	103	41	2011	184	1
12	Joint High Speed Vessel (JHSV)	376	2397	80	103	41	2012	376	1
13	Joint High Speed Vessel (JHSV)	207	2397	80	103	41	2013	207	1
14	LHA 6 America	3204	45695	37	114.91	1,687	2007	3,204	1
15	LHA 6 America	3213	45695	37	114.91	1,687	2011	3,213	1
16	Littoral Combat Ship	1077	3292	87	115.3	45	2010	1,077	1
17	Littoral Combat Ship	1147	3293	87	115.3	45	2011	1,147	1
18	Littoral Combat Ship	1858	3294	87	115.3	45	2012	1,858	1
19	Littoral Combat Ship	1821	3295	87	115.3	45	2013	1,821	1
20	LPD 17 San Antonio Class	1903	25300	39	208.5	360	2009	1,903	1
21	LPD 17 San Antonio Class	2088	25300	39	208.5	360	2012	2,088	1
22	USS Ticonderoga (CG 47)	1000	9754	56	173	30	2008	1,000	1
23	DD-21 Zumwalt	2700	16000	56	170	150	1996	2,700	1
24	Nimitz Class Aircraft Carrier (CVN 68)	4045	99800	56	332.8	558	2009	4,045	1
25	Nimitz Class Aircraft Carrier (CVN 68)	3421.3	99800	56	332.8	558	2011	3,421	1
26	Nimitz Class Aircraft Carrier (CVN 68)	4568.8	99800	56	332.8	558	2012	4,569	1
27	Nimitz Class Aircraft Carrier (CVN 68)	4738.2	99800	56	332.8	558	2016	4,738	1

Similar methodology in "Why Has the Cost of Navy Ships Risen?" RAND National Defense Research Institute 2006
Data Source: http://www.bga-aeroweb.com/Defense/DDG-51-AEGIS-Destroyer.html
http://www.globalsecurity.org/military/systems/ship/ddg-51.htm
http://www.defenseindustrydaily.com/adding-arleigh-burkes-northrop-grumman-underway-06007/

Econometric Analysis (Multivariate Regression Statistics)

Regression Analysis Report

Regression Statistics	
R-Squared (Coefficient of Determination)	0.8260
Adjusted R-Squared	0.7943
Multiple R (Multiple Correlation Coefficient)	0.9088
Standard Error of the Estimates (SEy)	585.1570
Number of Observations	27

The R-Squared or Coefficient of Determination indicates that 0.83 of the variation in the dependent variable can be explained and accounted for by the independent variables in this regression analysis. However, in a multiple regression, the Adjusted R-Squared takes into account the existence of additional independent variables or regressors and adjusts this R-Squared value to a more accurate view of the regression's explanatory power. Hence, only 0.79 of the variation in the dependent variable can be explained by the regressors.

The Multiple Correlation Coefficient (Multiple R) measures the correlation between the actual dependent variable (Y) and the estimated or fitted (Y) based on the regression equation. This is also the square root of the Coefficient of Determination (R-Squared).
The Standard Error of the Estimates (SEy) describes the dispersion of data points above and below the regression line or plane. This value is used as part of the calculation to obtain the confidence interval of the estimates later.

Regression Results

	Intercept	Displacement (Tons)	Speed (KMH)	Length (M)	Crew
Coefficients	-11837.1869	-0.1034	80.4366	55.5622	6.0975
Standard Error	4077.1440	0.0365	29.5533	15.4242	1.7271
t-Statistic	-2.9033	-2.8328	2.7217	3.6023	3.5306
p-Value	0.0082	0.0097	0.0125	0.0016	0.0019
Lower 5%	-20292.6660	-0.1791	19.1467	23.5743	2.5158
Upper 95%	-3381.7078	-0.0277	141.7265	87.5501	9.6793

Degrees of Freedom	
Degrees of Freedom for Regression	4
Degrees of Freedom for Residual	22
Total Degrees of Freedom	26

Hypothesis Test	
Critical t-Statistic (99% confidence with df of 22)	2.8188
Critical t-Statistic (95% confidence with df of 22)	2.0739
Critical t-Statistic (90% confidence with df of 22)	1.7171

The Coefficients provide the estimated regression intercept and slopes. For instance, the coefficients are estimates of the true; population b values in the following regression equation Y = b0 + b1X1 + b2X2 + ... + bnXn. The Standard Error measures how accurate the predicted Coefficients are, and the t-Statistics are the ratios of each predicted Coefficient to its Standard Error.

The t-Statistic is used in hypothesis testing, where we set the null hypothesis (Ho) such that the real mean of the Coefficient = 0, and the alternate hypothesis (Ha) such that the real mean of the Coefficient is not equal to 0. A t-test is is performed and the calculated t-Statistic is compared to the critical values at the relevant Degrees of Freedom for Residual. The t-test is very important as it calculates if each of the coefficients is statistically significant in the presence of the other regressors. This means that the t-test statistically verifies whether a regressor or independent variable should remain in the regression or it should be dropped.

The Coefficient is statistically significant if its calculated t-Statistic exceeds the Critical t-Statistic at the relevant degrees of freedom (df). The three main confidence levels used to test for significance are 90%, 95% and 99%. If a Coefficient's t-Statistic exceeds the Critical level, it is considered statistically significant. Alternatively, the p-Value calculates each t-Statistic's probability of occurrence, which means that the smaller the p-Value, the more significant the Coefficient. The usual significant levels for the p-Value are 0.01, 0.05, and 0.10, corresponding to the 99%, 95%, and 90% confidence levels.

The Coefficients with their p-Values highlighted in blue indicate that they are statistically significant at the 90% confidence or 0.10 alpha level, while those highlighted in red indicate that they are not statistically significant at any other alpha levels.

Regression Analysis – Auto Econometrics (Parametric Nonlinear Models)

Auto Econometrics

Regression Statistics	
R-Squared (Coefficient of Determination)	0.9383
Adjusted R-Squared	0.9198
Multiple R (Multiple Correlation Coefficient)	0.9687
Standard Error of the Estimates (SEy)	365.4465
Number of Observations	27

The R-Squared or Coefficient of Determination indicates that 0.94 of the variation in the dependent variable can be explained and accounted for by the independent variables in this regression analysis. However, in a multiple regression, the Adjusted R-Squared takes into account the existence of additional independent variables or regressors and adjusts this R-Squared value to a more accurate view of the regression's explanatory power. Hence, only 0.92 of the variation in the dependent variable can be explained by the regressors.

The Multiple Correlation Coefficient (Multiple R) measures the correlation between the actual dependent variable (Y) and the estimated or fitted (Y) based on the regression equation. This is also the square root of the Coefficient of Determination (R-Squared).

The Standard Error of the Estimates (SEy) describes the dispersion of data points above and below the regression line or plane. This value is used as part of the calculation to obtain the confidence interval of the estimates later.

Regression Results

	Intercept	var2	var4	var5	ln(var2)	ln(var3)	ln(var4)
Coefficients	86373.8318	-0.3741	302.1790	4.3956	7108.9055	9778.0160	-46327.8077
Standard Error	47165.1982	0.1184	108.1814	2.0715	1589.3175	1852.4014	16303.5560
t-Statistic	1.8313	-3.1603	2.7933	2.1220	4.4729	5.2786	-2.8416
p-Value	0.0820	0.0049	0.0112	0.0465	0.0002	0.0000	0.0101
Lower 5%	-12011.0457	-0.6211	76.5165	0.0746	3793.6472	5913.9744	-80336.4289
Upper 95%	184758.7092	-0.1272	527.8414	8.7166	10424.1637	13642.0575	-12319.1865

Degrees of Freedom	
Degrees of Freedom for Regression	6
Degrees of Freedom for Residual	20
Total Degrees of Freedom	26

Hypothesis Test	
Critical t-Statistic (99% confidence with df of 20)	2.8453
Critical t-Statistic (95% confidence with df of 20)	2.0860
Critical t-Statistic (90% confidence with df of 20)	1.7247

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Data Analysis and Probability Distribution Fitting

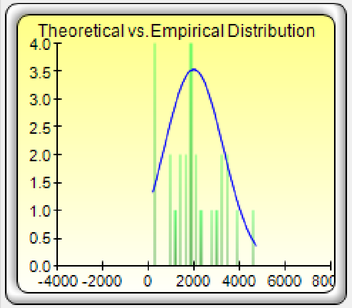
Multivariate Analysis (Warship Prices)

ID	Navy Ship	Unit Cost ($M)	Displacement (Tons)	Speed (KMH)	Length (M)	Crew	Year	Value	Q
1	DDG 51	2133	9648						1
2	DDG 51	1553	9648						2
3	DDG 51	1884	9648						1
4	DDG 51	1423	9648						3
5	DDG 51	2372	9648						1
6	DDG 51	1615	9648						1
7	DDG 51	1330.5	9648						2
8	DDG 1000	3554	15730						1
9	DDG 1000	3010	15730						1
10	Joint High Speed Vessel (JHSV)	185	2397						1
11	Joint High Speed Vessel (JHSV)	184	2397						1
12	Joint High Speed Vessel (JHSV)	376	2397						1
13	Joint High Speed Vessel (JHSV)	207	2397						1
14	LHA 6 America	3204	45695						1
15	LHA 6 America	3213	45695						1
16	Littoral Combat Ship	1077	3292						1
17	Littoral Combat Ship	1147	3293						1
18	Littoral Combat Ship	1858	3294						1
19	Littoral Combat Ship	1821	3295						1
20	LPD 17 San Antonio Class	1903	25300						1
21	LPD 17 San Antonio Class	2088	25300						1
22	USS Ticonderoga (CG 47)	1000	9754						1
23	DD-21 Zumwalt	2700	16000						1
24	Nimitz Class Aircraft Carrier (CVN 68)	4045	99800						1
25	Nimitz Class Aircraft Carrier (CVN 68)	3421.3	99800						1
26	Nimitz Class Aircraft Carrier (CVN 68)	4568.8	99800						1
27	Nimitz Class Aircraft Carrier (CVN 68)	4738.2	99800						1

Distribution Fitting Result

Distribution	Test Statistics	P-Value	Rank
Gumbel Maximum	0.07	99.84 %	1
Normal	0.09	98.49 %	2
Cosine	0.09	98.33 %	3
PERT	0.09	97.49 %	4
Parabolic	0.10	92.70 %	5
Laplace	0.11	89.30 %	6
Lognormal	0.11	84.59 %	7
Triangular	0.12	84.40 %	8
Gumbel Minimum	0.12	84.29 %	9
Gamma	0.12	83.33 %	10
Lognormal 3	0.12	82.27 %	11
Cauchy	0.12	79.54 %	12
Uniform	0.13	70.73 %	13
Pearson VI	0.14	60.74 %	14
Exponential 2	0.15	55.93 %	15
Double Log	0.16	46.45 %	16

Statistical Summary



Normal
Mean = 1990.74
Standard Deviation = 1290.26

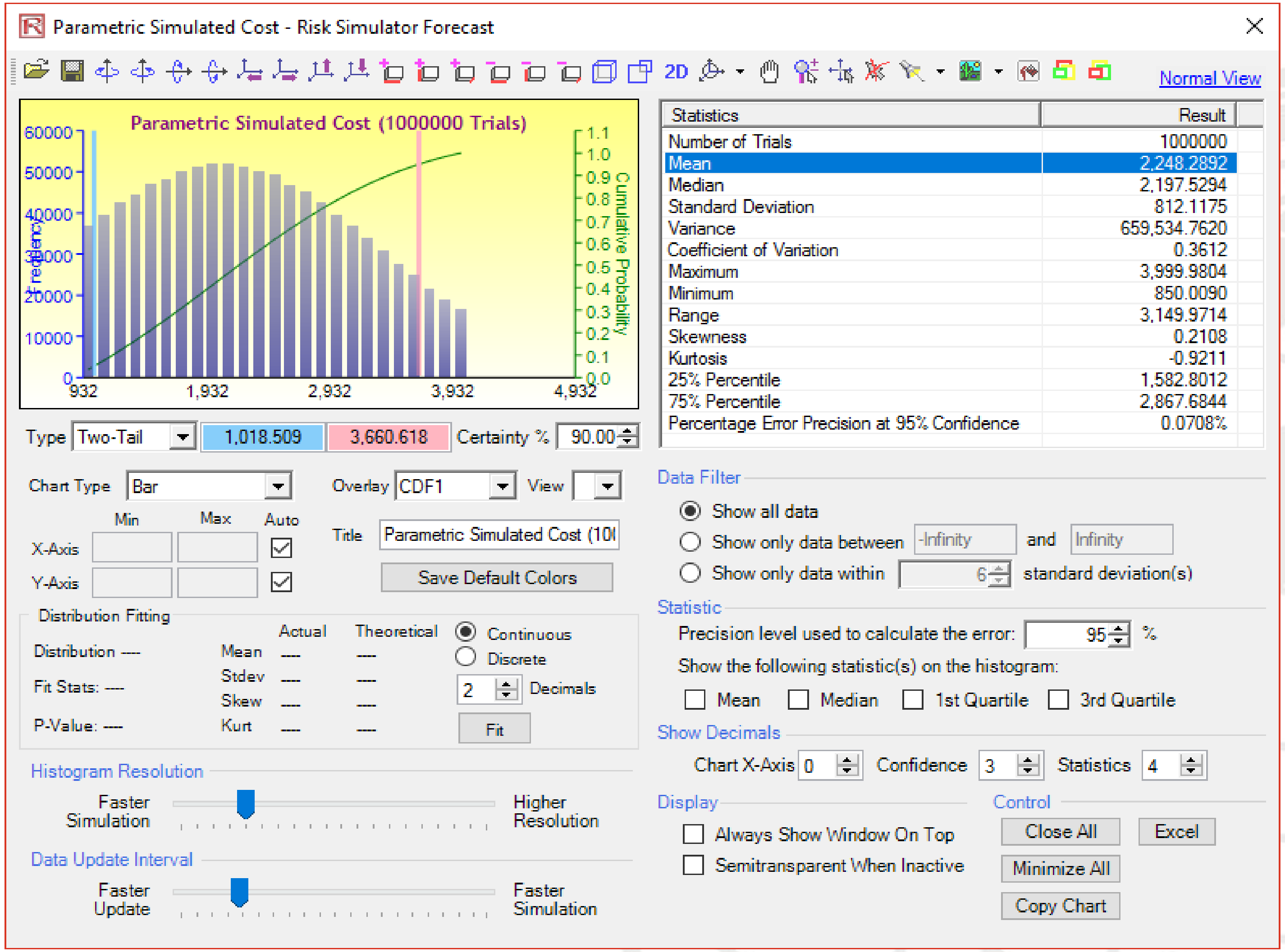
Kolmogorov-Smirnov Test Statistic
Test Statistic: 0.09
P-Value: 98.49 %

	Actual	Theoretical
Mean	2096.70	1990.74
Stdev	1290.26	1290.26
Skewness	0.39	0.00
Kurtosis	-0.51	0.00

Automatically Generate Assumption   OK   Cancel

Similar methodology in "Why Has the Cost of Navy Ships Risen?" RAND National Defense Research Institute 2006
Data Source: http://www.bga-aeroweb.com/Defense/DDG-51-AEGIS-Destroyer.html
http://www.globalsecurity.org/military/systems/ship/ddg-51.htm
http://www.defenseindustrydaily.com/adding-arleigh-burkes-northrop-grumman-underway-06007/

Monte Carlo Simulation and Uncertainty Analysis



Yes, there's tons of advanced math involved…

	$Z_t \sim$ Normal Distribution	$Z_t \sim$ T-Distribution
GARCH-M Variance in Mean Equation	$y_t = c + \lambda\sigma_t^2 + \varepsilon_t$ $\varepsilon_t = \sigma_t z_t$ $\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2$	$y_t = c + \lambda\sigma_t^2 + \varepsilon_t$ $\varepsilon_t = \sigma_t z_t$ $\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2$
GARCH-M Standard Deviation in Mean Equation	$y_t = c + \lambda\sigma_t + \varepsilon_t$ $\varepsilon_t = \sigma_t z_t$ $\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2$	$y_t = c + \lambda\sigma_t + \varepsilon_t$ $\varepsilon_t = \sigma_t z_t$ $\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2$
GARCH-M Log Variance in Mean Equation	$y_t = c + \lambda\ln(\sigma_t^2) + \varepsilon_t$ $\varepsilon_t = \sigma_t z_t$ $\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2$	$y_t = c + \lambda\ln(\sigma_t^2) + \varepsilon_t$ $\varepsilon_t = \sigma_t z_t$ $\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2$
GARCH	$y_t = x_t\gamma + \varepsilon_t$ $\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2$	$y_t = \varepsilon_t$ $\varepsilon_t = \sigma_t z_t$ $\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2$
EGARCH	$y_t = \varepsilon_t$ $\varepsilon_t = \sigma_t z_t$ $\ln(\sigma_t^2) = \omega + \beta \cdot \ln(\sigma_{t-1}^2) +$ $\alpha\left[\left\lvert\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right\rvert - E(\lvert\varepsilon_t\rvert)\right] + r\frac{\varepsilon_{t-1}}{\sigma_{t-1}}$ $E(\lvert\varepsilon_t\rvert) = \sqrt{\frac{2}{\pi}}$	$y_t = \varepsilon_t$ $\varepsilon_t = \sigma_t z_t$ $\ln(\sigma_t^2) = \omega + \beta \cdot \ln(\sigma_{t-1}^2) +$ $\alpha\left[\left\lvert\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right\rvert - E(\lvert\varepsilon_t\rvert)\right] + r\frac{\varepsilon_{t-1}}{\sigma_{t-1}}$ $E(\lvert\varepsilon_t\rvert) = \frac{2\sqrt{\nu-2}\,\Gamma((\nu+1)/2)}{(\nu-1)\Gamma(\nu/2)\sqrt{\pi}}$
GJR-GARCH	$y_t = \varepsilon_t$ $\varepsilon_t = \sigma_t z_t$ $\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 +$ $r\varepsilon_{t-1}^2 d_{t-1} + \beta\sigma_{t-1}^2$ $d_{t-1} = \begin{cases} 1 & \text{if } \varepsilon_{t-1} < 0 \\ 0 & \text{otherwise} \end{cases}$	$y_t = \varepsilon_t$ $\varepsilon_t = \sigma_t z_t$ $\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 +$ $r\varepsilon_{t-1}^2 d_{t-1} + \beta\sigma_{t-1}^2$ $d_{t-1} = \begin{cases} 1 & \text{if } \varepsilon_{t-1} < 0 \\ 0 & \text{otherwise} \end{cases}$

The Brownian motion random walk process takes the form of $\frac{\delta S}{S} = \mu(\delta t) + \sigma\varepsilon\sqrt{\delta t}$ for regular options simulation, or a more generic version takes the form of $\frac{\delta S}{S} = (\mu - \sigma^2/2)\delta t + \sigma\varepsilon\sqrt{\delta t}$ for a geometric process. For an exponential version, we simply take the exponentials, and as an example, we have $\frac{\delta S}{S} = \exp\left[\mu(\delta t) + \sigma\varepsilon\sqrt{\delta t}\right]$.

The following are the variable definitions:

- S as the variable's previous value
- δS as the change in the variable's value from one step to the next
- μ as the annualized growth or drift rate
- σ as the annualized volatility

In order to estimate the parameters from a set of time-series data, the drift rate and volatility can be found by setting μ to be the average of the natural logarithm of the relative returns $ln\frac{S_t}{S_{t-1}}$, while σ is the standard deviation of all $ln\frac{S_t}{S_{t-1}}$ values.

Autoregressive Integrated Moving Average or ARIMA(p,d,q) models are the extension of the AR model that uses three components for modeling the serial correlation in the time series data. The first component is the autoregressive (AR) term. The AR(p) model uses the p lags of the time series in the equation. An AR(p) model has the form: $y_t = a_1 y_{t-1} + \ldots + a_p y_{t-p} + e_t$. The second component is the integration (d) order term. Each integration order corresponds to differencing the time series. I(1) means differencing the data once. I(d) means differencing the data d times. The third component is the moving average (MA) term. The MA(q) model uses the q lags of the forecast errors to improve the forecast. An MA(q) model has the form: $y_t = e_t + b_1 e_{t-1} + \ldots + b_q e_{t-q}$. Finally, an ARMA(p,q) model has the combined form: $y_t = a_1 y_{t-1} + \ldots + a_p y_{t-p} + e_t + b_1 e_{t-1} + \ldots + b_q e_{t-q}$.

Conclusions

- This Cost Modeling methodology and supporting toolset can be used to monitor project activities, costs (total, fixed, and variable), and schedule to build U.S. Navy Ships within an integrated risk management approach.
- Based on publicly available information and aligned to our estimations (*bottom-up* and *top-down*), the next generation of U.S. Navy Destroyer Ships could cost between $2.04B and $3.18B each (90% confidence) including managerial, administrative, support, and commissioning activities. Prices decrease with bulk orders due to synergy and flatter learning curves.
- The project implementation (schedule), considering the complex integration of the Air and Missile Defense Radar (AMDR) systems, the Electronic Warfare Systems (EWS), and the Fire Control Systems (e.g., in the AEGIS and MK), could be completed between 107 and 147 weeks (90% confidence).
- The literature and our estimations reveal that the development and integration of Radar and Weapons Systems, and the assembly and erection of Warship sections are critical to successfully develop U.S. Navy Destroyers.

Recommendations

- Although this study relies on publicly available information for the cost and schedule modeling, it requires updated and more specific project management information from the incumbent decision makers, previous DDG projects and Navy Ships specifications, and Contractors & U.S. Navy project controls and deliverables to better calibrate the models and to improve the estimations.
- Using the proposed methodology and cost modeling approach, decision makers can accurately visualize the milestones and risks in U.S. Navy shipbuilding. Therefore, the U.S. Navy can make use of these project economic analysis tools (cost and schedule, multivariate analysis and auto econometrics, risk analysis, simulations, and project portfolios and sections management, among other aspects) to better control its acquisitions, capital investments, and capital budgeting in warship building.

Next Steps

- Collecting and using actual cost data and better cost estimates going forward in order to better calibrate the inputs based on real-life conditions. (We can provide inputs and suggestions on how to generate a database and methods to capture said required data.)
- Using the simulated probability distributions to determine how well the vendors are performing (e.g., running at 92% efficiency etc.), thus creating level of performance metrics for the organization.
- Using control charts (based on simulated results) to determine if any processes and tasks are in-control or out-of-control over time.
- Identifying critical success factors to start collecting cost and schedule data for better estimates.
- Incorporating learning curves and synergies when more than one ship is in order and the unit cost per ship would be lower.

NAVAL
POSTGRADUATE
SCHOOL

APPENDIX
Analytical Details

Abstract

This research project pertains to the development of alternative ship cost modeling methodologies. Most ship cost modeling has been traditionally weight-based. This approach drives the U.S. Navy to select smaller ships that, consequently, require custom-designed shipboard components. This research project is intended to help determine if there is a more accurate way to empirically predict, forecast, and model ship cost. Current and forecasted Department of Defense (DOD) budgets require identifying, modeling, and estimating the costs of shipbuilding. Information and data were obtained via publicly available sources and were collected, collated, and used in an integrated risk-based cost and schedule modeling methodology. The objective of this study is to develop a comprehensive cost modeling strategy and approach, and, as such, notional data were used. Specifically, we used the Arleigh Burke Class Guided Missile Destroyer DDG 51 Flight I, Flight II, Flight IIA, and Flight III as a basis for the cost and schedule assumptions, but the modeling approach is extensible to any and all other ships within the U.S. Navy. The results will be used to develop recommendations and develop a cost modeling tool on how to implement ship cost forecasts. This example will provide a roadmap for other new ship cost modeling by the U.S. Navy, thereby improving effectiveness and increasing cost savings.

- Overview of U.S. Navy Ships (DDG 51 Destroyer Class)
- Department of Defense (DoD) Budget Data
- Global Costs and Scheduling Perspective
- Scheduling Information from BIW Contractor (GAO)
- Process Flow: Planning, Design, Construction, Integration, Trials & Commissioning

Cost Modeling (Research and Data Analysis)

Cost Information on Electrical, Radars (AMDR), Electronic Warfare, Fire Control, and Additional Systems

Category	*Items*	*Quantity*	*Min Unit Cost*	*Aveg Unit Cost*	*Max Unit Cost*	*Total Cost ($M)*
Energy Systems	LM2500 GE Marine Gas Turbines 105,000 shp (90,000 sust.)	4	2.000	2.5	3.000	10.00
	3 Allison 2500 KW Gas Turbine Generators	3	0.280	0.35	0.420	1.05
	2 Shafts with CRP (Controllable Reversible Pitch) Propellers	2				
	2 5-blade CP Rudders	2				
	SSGTG (Ship Service Gas Turbine Generators)	1				
	High Power Generation Plants	1				
	High Power Efficiency AC Plants	1				
Total		***14.00***	***2.28***	***2.85***	***3.42***	***11.05***
	AN/SPY-6(V) Air and Missile Defense Radar (AMDR)					
Radar Systems	Air & Missile Defense Radar (A&MD Radar) and Combat System Integrator	1	308.560	385.70	462.840	385.70
Total		***1.00***	***308.56***	***385.70***	***462.84***	***385.70***
Electronic warfare & decoys	AN/SLQ-32(V)2 Electronic Warfare System	1	2.000	2.5	3.000	2.50
	AN/SLQ-25 Nixie Torpedo Countermeasures					
	MK 36 MOD 12 Decoy Launching System					
	AN/SLQ-39 CHAFF Buoys					
Total		***1.00***	***2.00***	***2.50***	***3.00***	***2.50***
Fire control	AEGIS Weapon System MK-7	1	51.240	42.7	51.240	42.70
	MK116 MOD 7 Underwater Fire Control System					
	AN/SQQ-89 ASW Combat System					
	AN/SWG-I A (V) Harpoon Launcher Control System					
	AN/SWG-3A TOMAHAWK Weapon Control System					
	MK 99 Fire Control System					
Total		***1.00***	***51.24***	***42.70***	***51.24***	***42.70***
Extra capabilities	Helo landing capability					
	Dual Hangars for organic Helo support					
	Rigid hull inflatable boats (Defender)	2	0.01	0.0175	0.025	0.04
Total		***2.00***	***0.01***	***0.02***	***0.03***	***0.04***
Support	Suppor services and Yard Admin	1	7	10	20	10.00
Total		***1.00***	***7.00***	***10.00***	***20.00***	***10.00***

Schedule and Costs of Global Warship Building

[M:\Client Projects\Navy and Department of Defense\2016-06 Cost Estimation for Ship Building\Models\Cost Estimation Models - Draft 2.rovprojecon] - PROJECT ECONOMICS ANALYSIS TOOL

File Edit Projects Report Tools Language Decimals Help

Welcome to the ROV Project Economics Analysis Tool (PEAT). This tool will help you set up a series of projects or capital investment options, model their cash flows, simulate their risks, and run advanced analytics, perform forecasting and prediction modeling, and optimize your investment portfolio subject to budgetary and other constraints.

Project Management | Applied Analytics | Risk Simulation | Options Strategies | Options Valuation | Forecast Prediction | Dashboard | Knowledge Center

Ship Building | ICT Navigation | Weapon Systems | Aircraft | Electrical Systems | Radar Systems | Extra Systems | Support Processes | Portfolio Analysis

Select the Project Schedule & Cost Risk Model to use: ○ Sequential Path ◉ Complex Network Path Project Name/Notes:

Network Diagram | Schedule & Cost

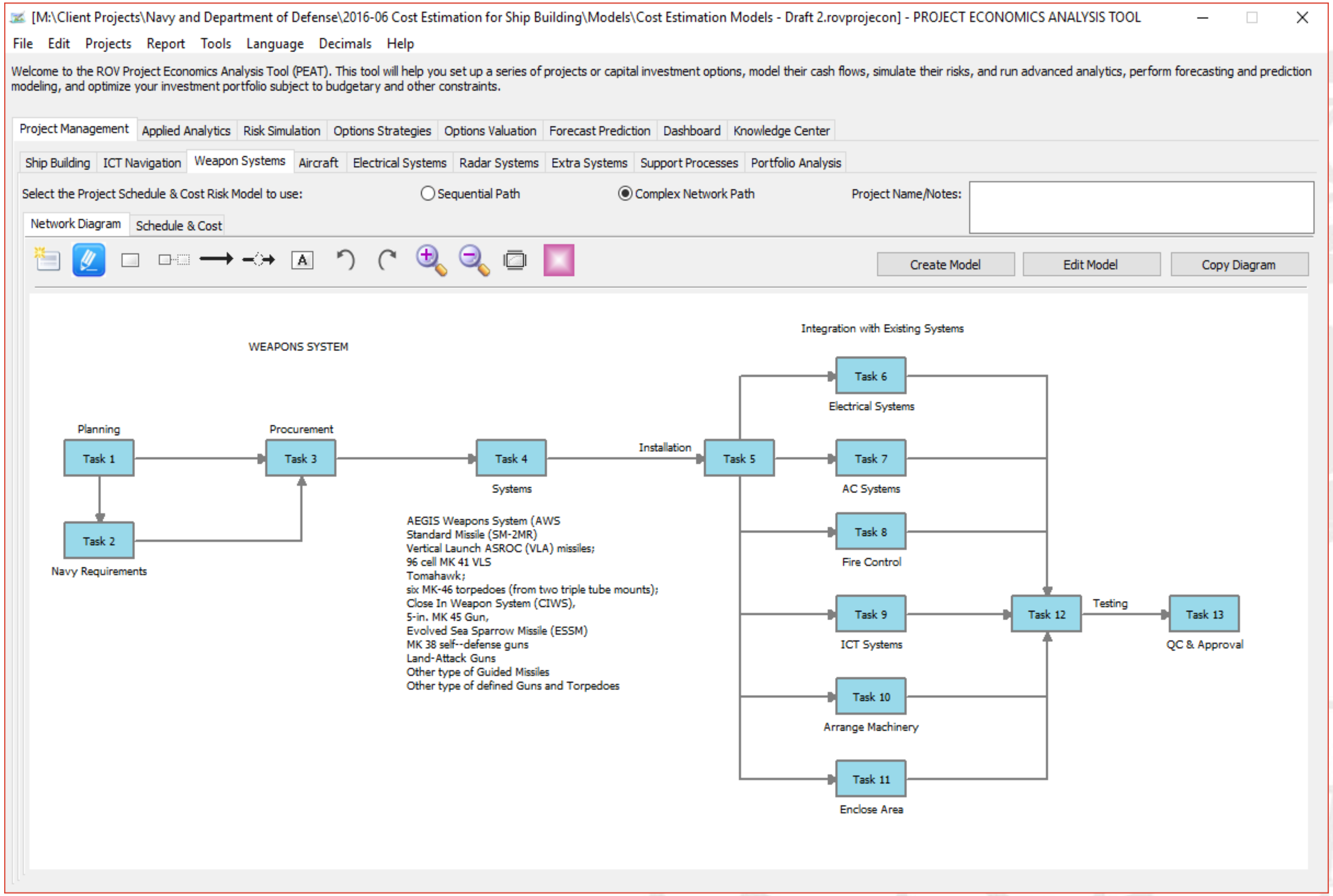
☑ Include Schedule-Based Cost Analysis
☑ Include Budget Overrun & Buffers
☐ Include Probabilities of Success of Each Task and Model Their Impacts
☑ Perform Risk Simulation

Run | Run All Projects

Show 27 Tasks with Weekly Simulation Trials: 1,000,000 ☑ Apply Seed Value: 123 Triangular

Task 6	Sheet Metal	19.70	24.62	29.55	27	1.27	2.00	2.73	0.04	10.00%
Task 7	Electrical Shop	19.70	24.62	29.55	29	3.17	5.00	6.84	0.40	10.00%
Task 8	Added Requirements	2.36	3.07	4.76	4	2.53	4.00	5.47	0.16	10.00%
Task 9	Yard Definition	2.63	3.41	5.29	4	2.53	4.00	5.47	0.16	10.00%
Task 10	Sections Definition	2.89	3.75	5.82	4	1.27	2.00	2.73	0.16	10.00%
Task 11	Prep & Fab	1.84	2.38	3.70	4	3.80	6.00	8.20	0.16	10.00%
Task 12	Sub Assembly	21.01	27.25	42.33	31	2.53	4.00	5.47	0.24	10.00%
Task 13	Transport	13.13	17.03	26.45	20	1.90	3.00	4.10	0.24	10.00%
Task 14	Assembly	31.51	40.88	63.49	47	3.17	5.00	6.84	0.40	10.00%
Task 15	Preoutfit Hot	13.13	17.03	26.45	20	1.90	3.00	4.10	0.24	10.00%
Task 16	Blast & Paint	3.15	4.09	6.35	5	1.90	3.00	4.10	0.24	10.00%
Task 17	Preoutfit Cold	2.63	3.41	5.29	4	1.27	2.00	2.73	0.16	10.00%
Task 18	Erect/Wet Berth	39.39	51.10	79.36	57	1.90	3.00	4.10	0.24	10.00%
Task 19	HME Global Testing	55.14	71.54	111.10	87	6.33	10.00	13.67	0.79	10.00%
Task 20	Electrical	4.40	11.05	17.70	20	17.07	44.00	70.93	0.16	10.00%
Task 21	Comm & Nav System	19.64	47.07	74.50	61	19.40	50.00	80.60	0.16	10.00%
Task 22	Radar & EWS	158.16	385.70	613.24	435	23.28	60.00	96.72	0.16	10.00%
Task 23	Weapon Systems	514.54	1,262.38	2,010.21	1,397	18.62	48.00	77.38	0.16	10.00%
Task 24	Aircraft	24.56	61.54	98.52	71	13.97	36.00	58.03	0.08	10.00%
Task 25	Extras	18.03	45.24	72.44	52	9.31	24.00	38.69	0.08	10.00%
Task 26	Sea Trials	42.01	54.50	84.65	74	5.06	8.00	10.94	1.59	10.00%
Task 27	QC & Approval	26.26	34.07	52.91	38	1.90	3.00	4.10	0.24	10.00%

WBS and Network Diagram (Weapons Systems)



Schedule and Costs of Global Warship Building (Weapons Systems)

[M:\Client Projects\Navy and Department of Defense\2016-06 Cost Estimation for Ship Building\Models\Cost Estimation Models - Draft 2.rovprojecon] - PROJECT ECONOMICS ANALYSIS TOOL

File Edit Projects Report Tools Language Decimals Help

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Project Management | Applied Analytics | Risk Simulation | Options Strategies | Options Valuation | Forecast Prediction | Dashboard | Knowledge Center

Ship Building | ICT Navigation | Weapon Systems | Aircraft | Electrical Systems | Radar Systems | Extra Systems | Support Processes | Portfolio Analysis

Select the Project Schedule & Cost Risk Model to use: ○ Sequential Path ◉ Complex Network Path Project Name/Notes:

Network Diagram | Schedule & Cost

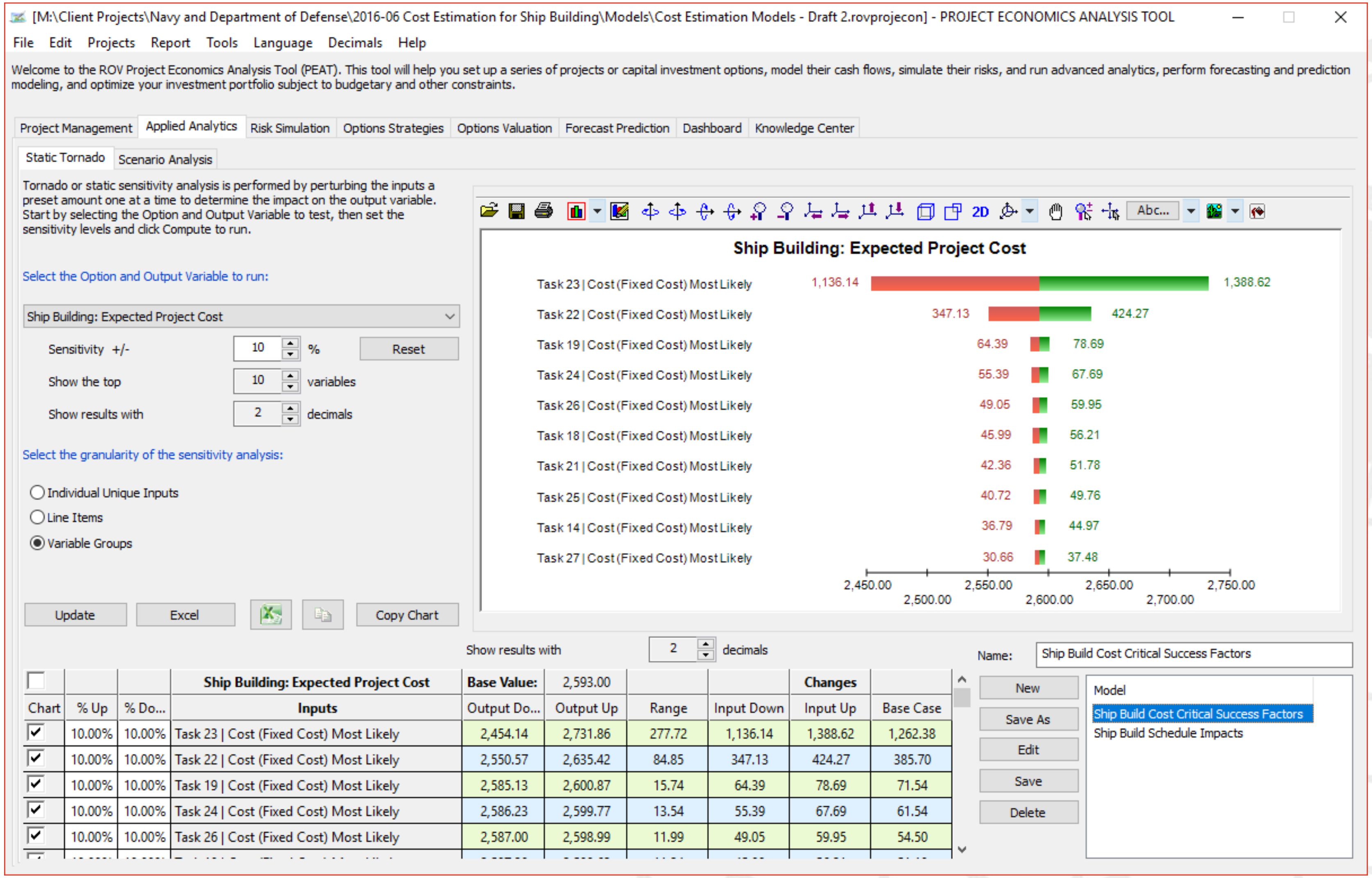
☑ Include Schedule-Based Cost Analysis ☐ Include Probabilities of Success of Each Task and Model Their Impacts

☑ Include Budget Overrun & Buffers ☑ Perform Risk Simulation Run | Run All Projects

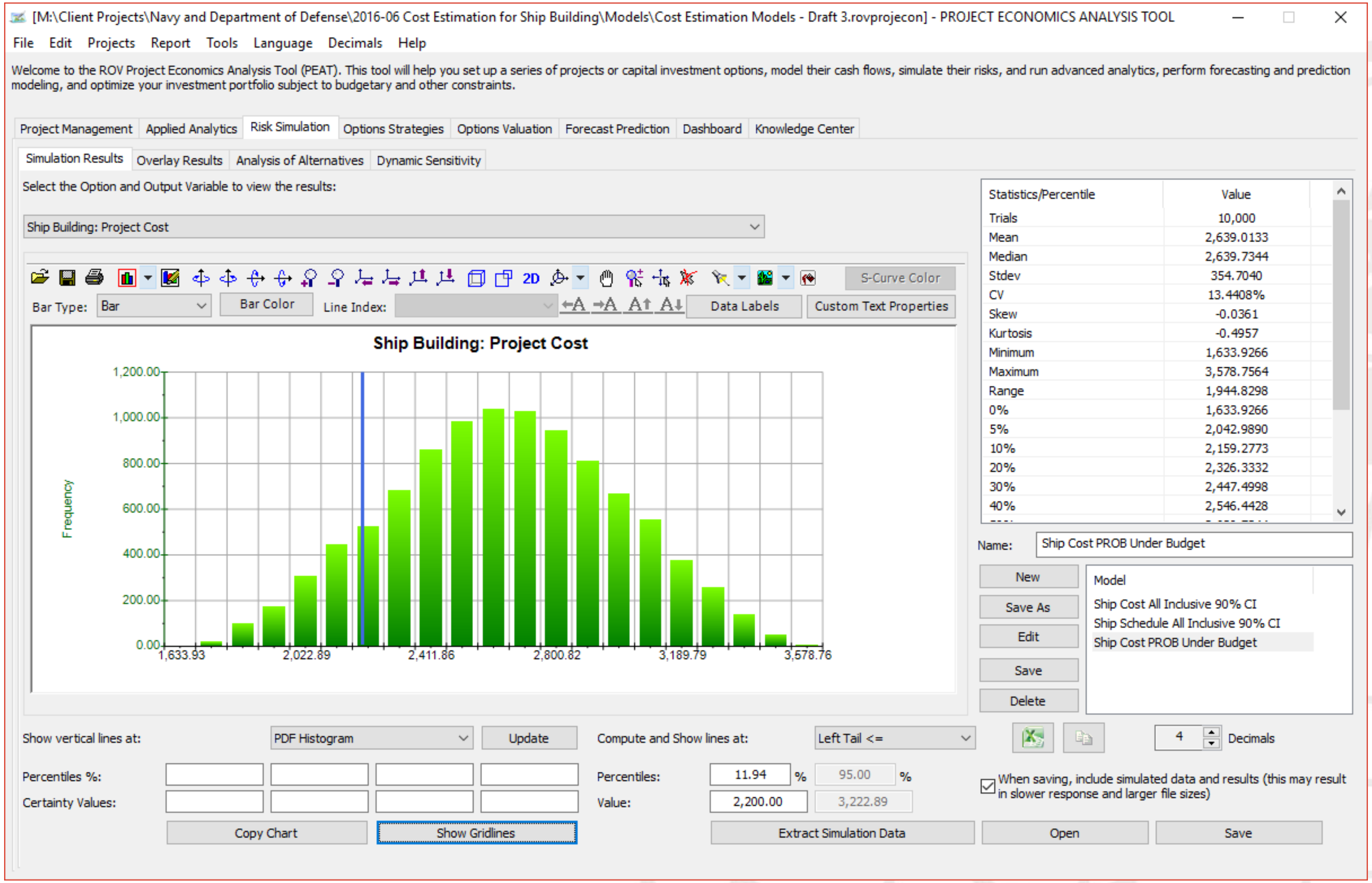
Show 16 Tasks with Weekly Simulation Trials: 1,000,000 ☑ Apply Seed Value: 123 Triangular

Task	Task Name	Cost (Fixed Cost) Minimum	Most Likely	Maximum	Computed Cost	Time Schedule (Weeks) Minimum	Most Likely	Maximum	Variable Weekly Cost	Overrun Assumption
Task 1	Planning	15.98	25.25	34.51	30	1.27	2.00	2.73	0.94	10.00%
Task 2	Navy Requirements	15.98	25.25	34.51	30	1.27	2.00	2.73	0.94	10.00%
Task 3	Procurement	7.35	18.94	30.52	25	1.55	4.00	6.45	0.94	10.00%
Task 4	Systems	342.86	883.66	1,424.46	997	9.31	24.00	38.69	0.94	10.00%
Task 5	Installation	12.25	31.56	50.87	39	1.55	4.00	6.45	0.94	10.00%
Task 6	Electrical Systems	19.59	50.50	81.40	62	2.33	6.00	9.67	0.94	10.00%
Task 7	AC Systems	9.80	25.25	40.70	36	3.10	8.00	12.90	0.94	10.00%
Task 8	Fire Control	14.69	37.87	61.05	48	2.33	6.00	9.67	0.94	10.00%
Task 9	ICT Systems	22.04	56.81	91.57	71	3.10	8.00	12.90	0.94	10.00%
Task 10	Arrange Machinery	19.98	31.56	43.14	43	5.06	8.00	10.94	0.94	10.00%
Task 11	Enclose Area	11.99	18.94	25.89	23	1.27	2.00	2.73	0.94	10.00%
Task 12	Testing	14.69	37.87	61.05	45	1.16	3.00	4.84	0.94	10.00%
Task 13	QC & Approval	7.35	18.94	30.52	22	0.39	1.00	1.61	0.94	10.00%
	Project Total Cost	**515**	**1,262**	**2,010**	**1,469**					
	Expected Total Duration					**34**	**48.00**	**122**		

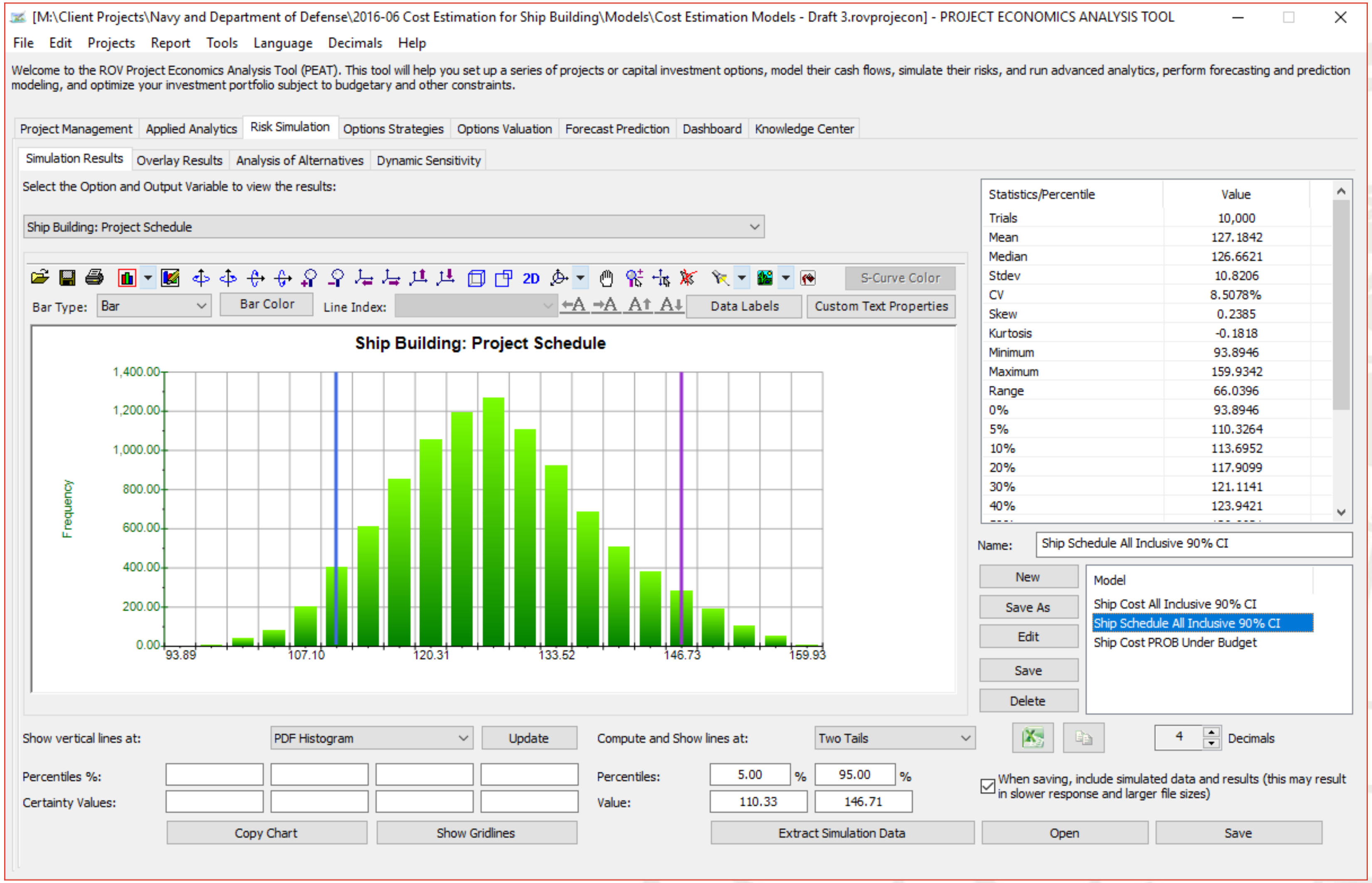
Expected Project Costs (Shipbuilding)



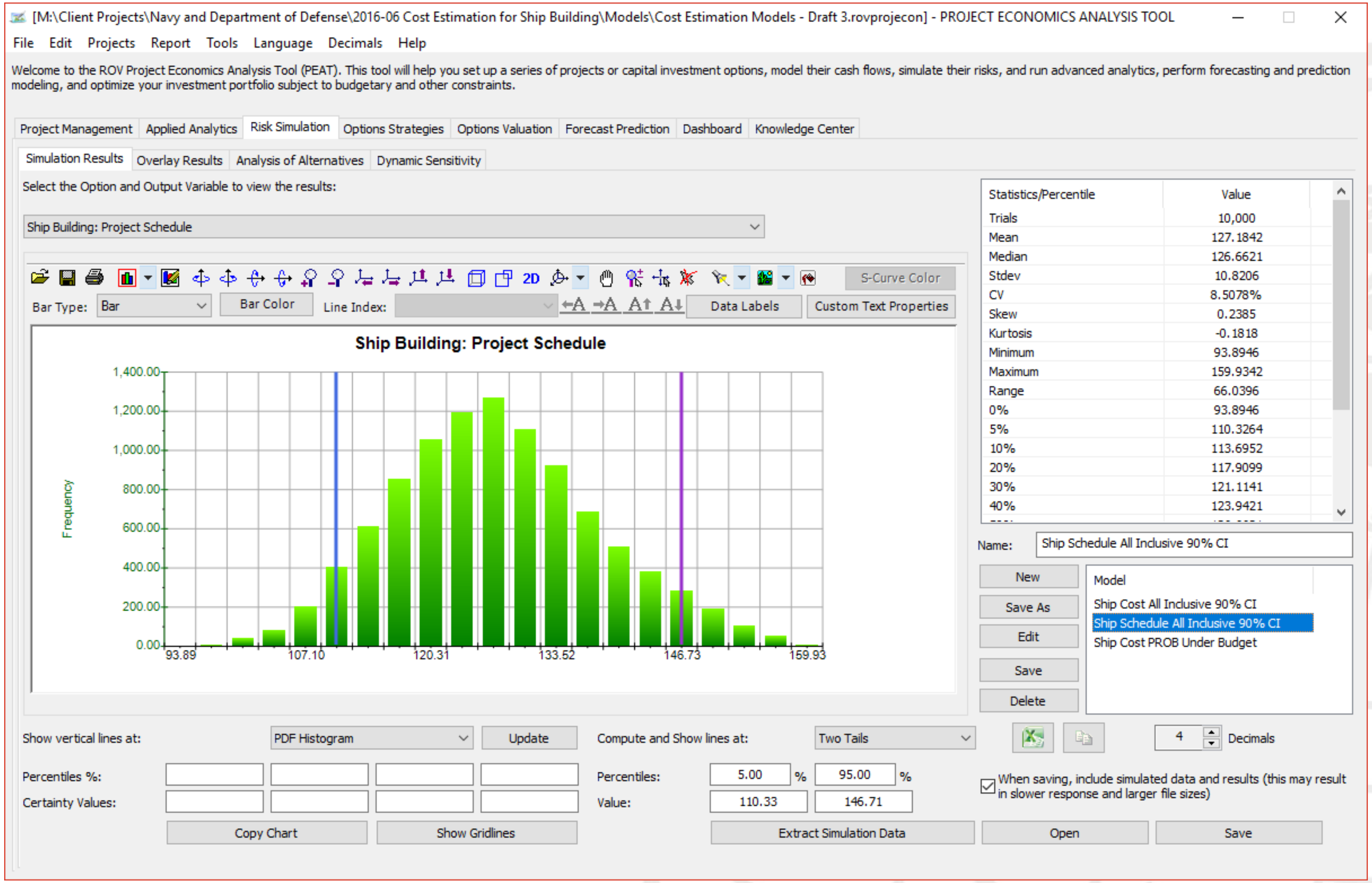
Expected Project Cost (Risk Profile)



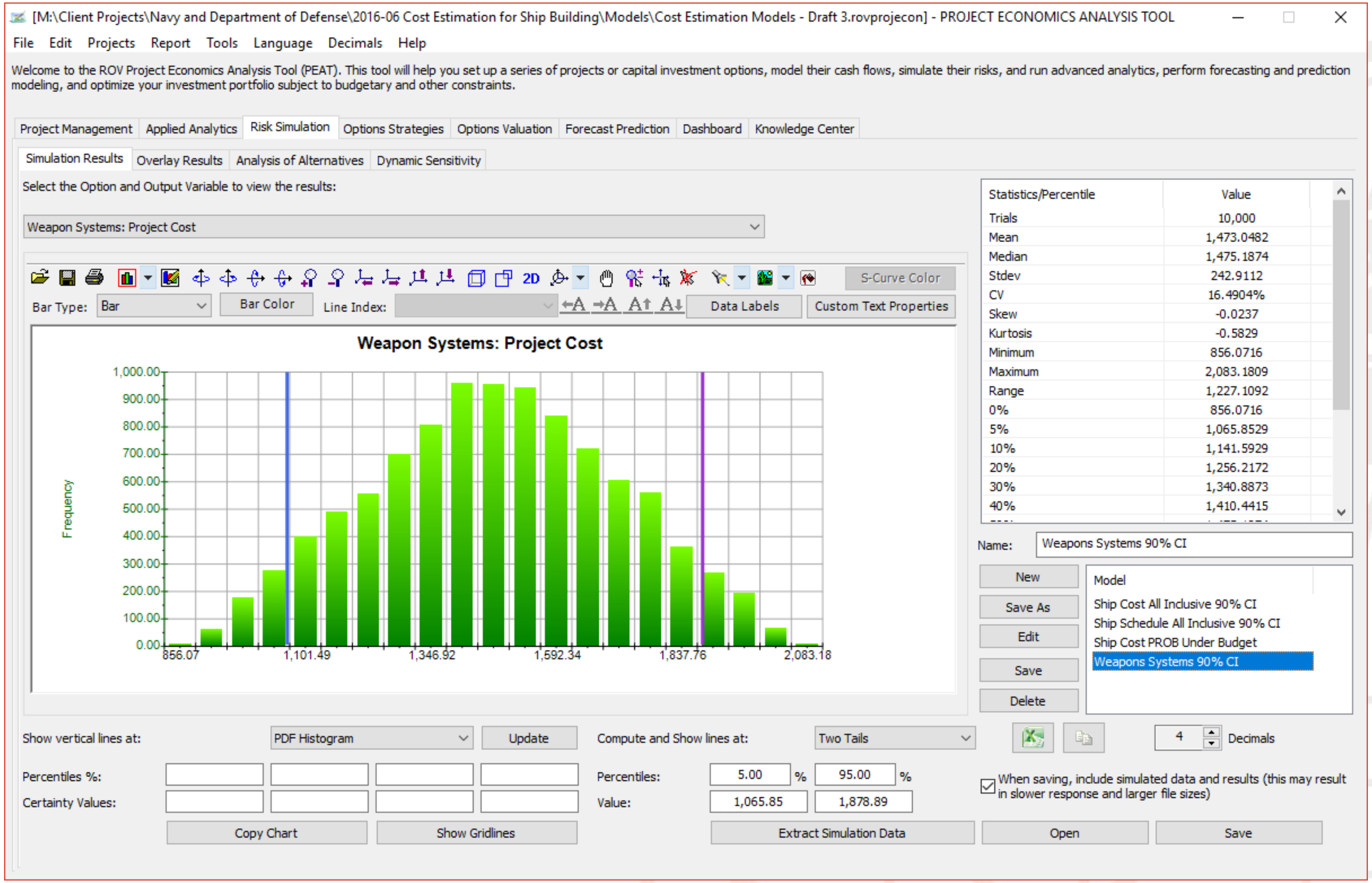
Expected Project Schedule (Risk Profile)



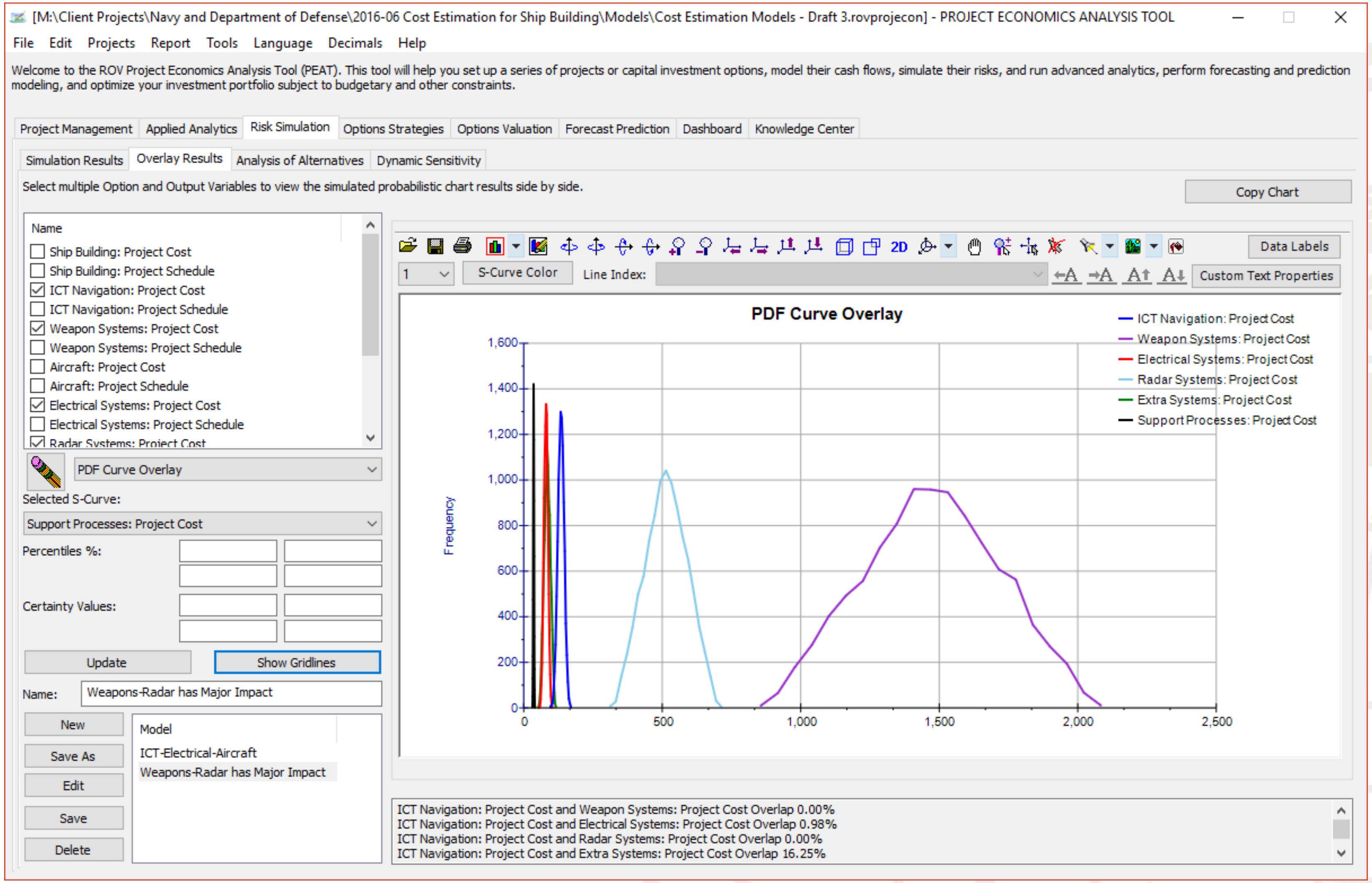
Expected Project Schedule (Risk Profile)



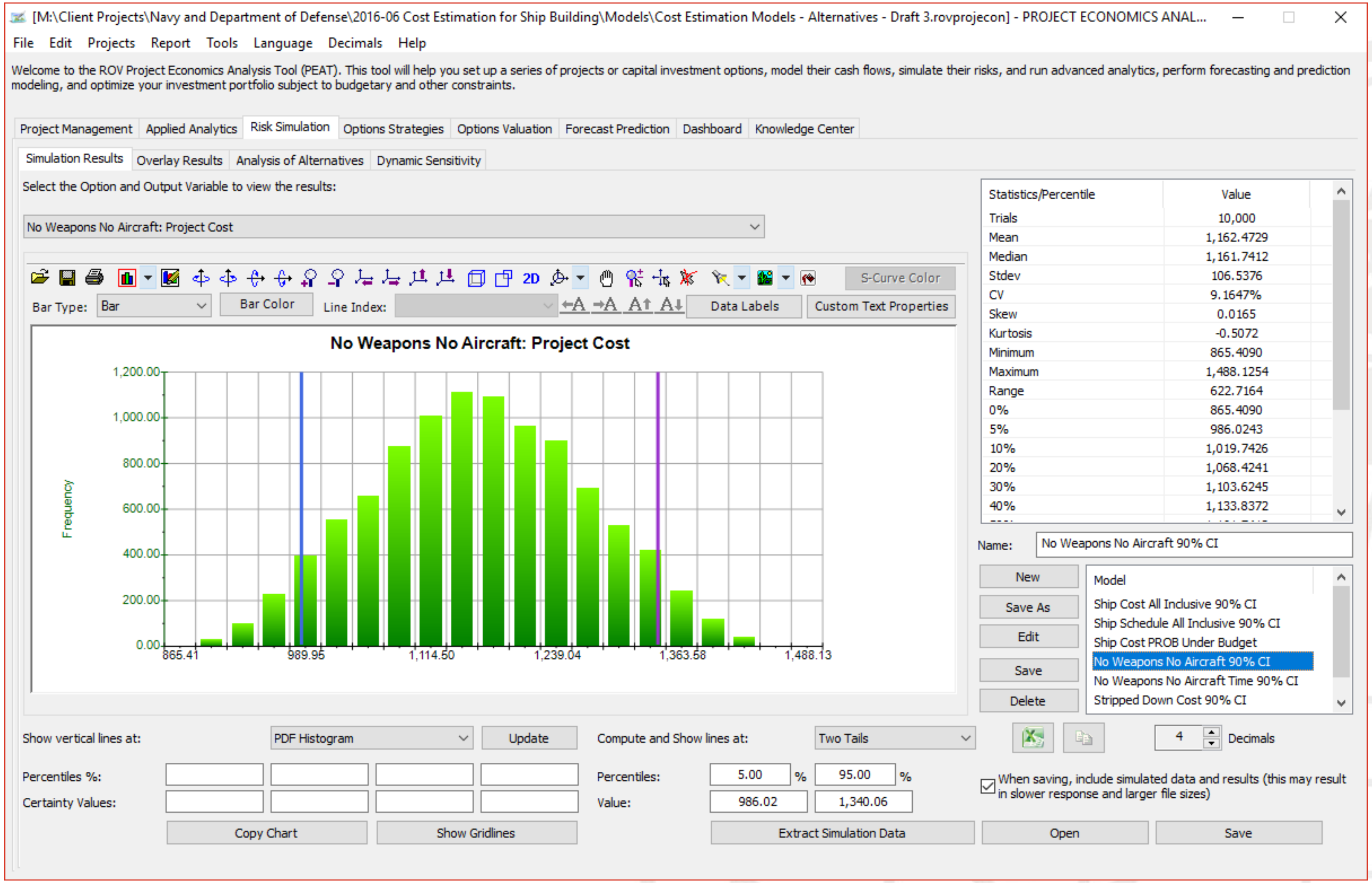
Expected Project Schedule (Risk Profile)



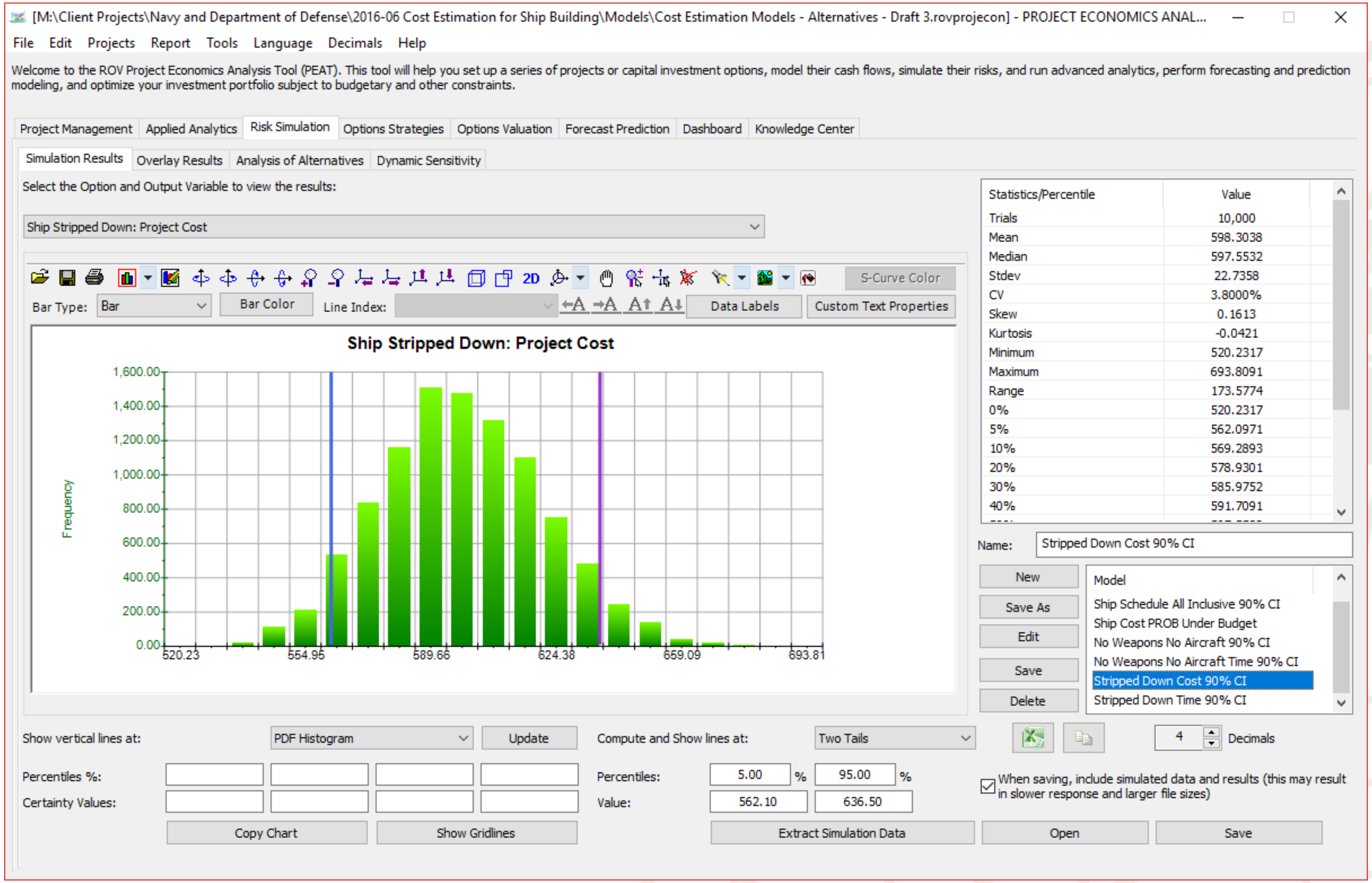
Project Cost by Sections (Overlays and Stochastic Dominance)



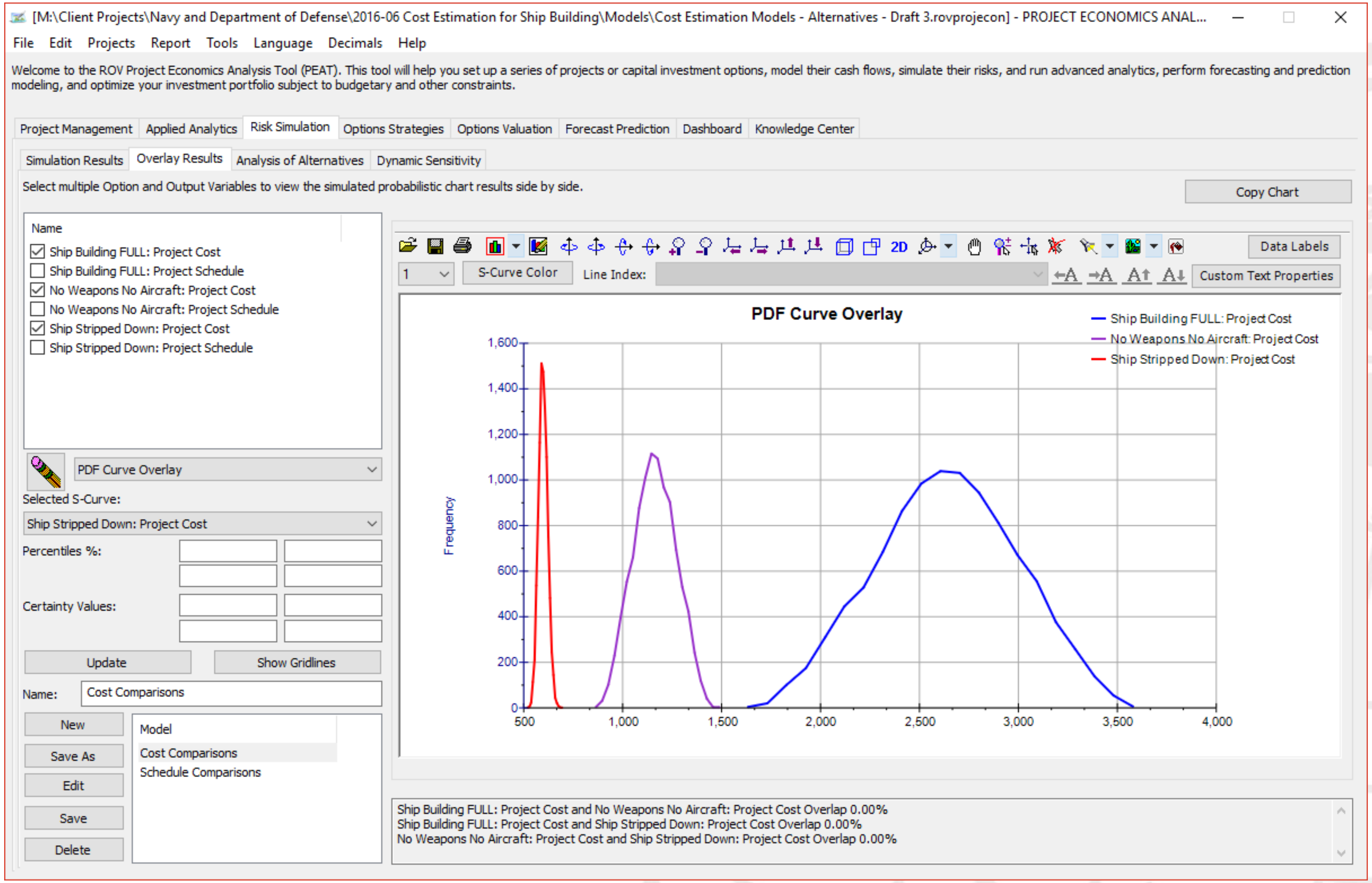
Project Cost by Predefined Configurations



Project Cost by Predefined Configurations



Project Risk Analysis (Costs Comparisons)



Global Costs and Scheduling Perspective

FY 2016 Program Acquisition Costs by Weapon System

DDG 51 ARLEIGH BURKE Class Destroyer **USN**

US Navy Photo

The DDG 51 class guided missile destroyers provide a wide range of warfighting capabilities in multi-threat air, surface, and subsurface environments. The DDG 51 class ship is armed with a vertical launching system, which accommodates 96 missiles, and a 5-inch gun that provides Naval Surface Fire Support to forces ashore and anti-ship gunnery capability against other ships. The DDG 51 class is the first class of destroyers with a ballistic missile defense capability. The Arleigh Burke class is comprised of four separate variants; DDG 51-71 represent the original design, designated Flight I ships, and are being modernized to current capability standards; DDG 72-78 are Flight II ships; DDG 79-123 ships are Flight IIA ships; and, in FY 2016, DDG-124 will become the first Flight III ship. Flight III ships will feature the Air and Missile Defense Radar (AMDR) capability.

Mission: Provides air and maritime dominance and land attack capability with its AEGIS Weapon System, AN/SQQ-89 Anti-Submarine Warfare System, and Tomahawk Weapon Systems.

FY 2016 Program: Funds two DDG 51 AEGIS class destroyers as part of a multiyear procurement for ten ships from FY 2013 - FY 2017.

OFFICE OF THE UNDER SECRETARY OF DEFENSE (COMPTROLLER)/CFO
FEBRUARY 2015

PROGRAM ACQUISITION COST BY WEAPON SYSTEM

UNITED STATES DEPARTMENT OF DEFENSE FISCAL YEAR 2016 BUDGET REQUEST

DDG 51 ARLEIGH BURKE Class Destroyer

	FY 2014		FY 2015		FY 2016 Base Budget		FY 2016 OCO Budget		FY 2016 Total Request	
	$M	Qty	$M	Qty	$M	Qty	$M	Qty	$M	Qty
RDT&E	183.3	-	87.1	-	183.3	-	-	-	183.3	-
Procurement	2,086.4	1	2,931.6	2	3,286.8	2	-	-	3,286.8	2
Total	2,269.7	1	3,018.7	2	3,470.1	2	-	-	3,470.1	2

Numbers may not add due to rounding

6-3 SHIPBUILDING AND MARITIME SYSTEMS

US Navy awards DDG 51 ships construction contracts

0

4 June 2013

The US Navy has awarded two contracts to General Dynamics (GD) Bath Iron Works (BIW) and Huntington Ingalls Industries (HII) to construct a total of nine DDG 51 Arleigh Burke-class guided missile ships, with an option for a tenth vessel in a Flight IIA configuration.

General Dynamics BIW has received a fixed-price incentive firm target contract worth $2.84bn for the design and construction of four DDG 51-class ships, one in 2013 and one each year from 2015-2017, as well as an option for a fifth ship.

http://www.navaltechnology.com/news/newsusnavyawardddg51shipsconstructioncontracts

Scheduling Information from BIW Contractor According to GAO

Design Delays

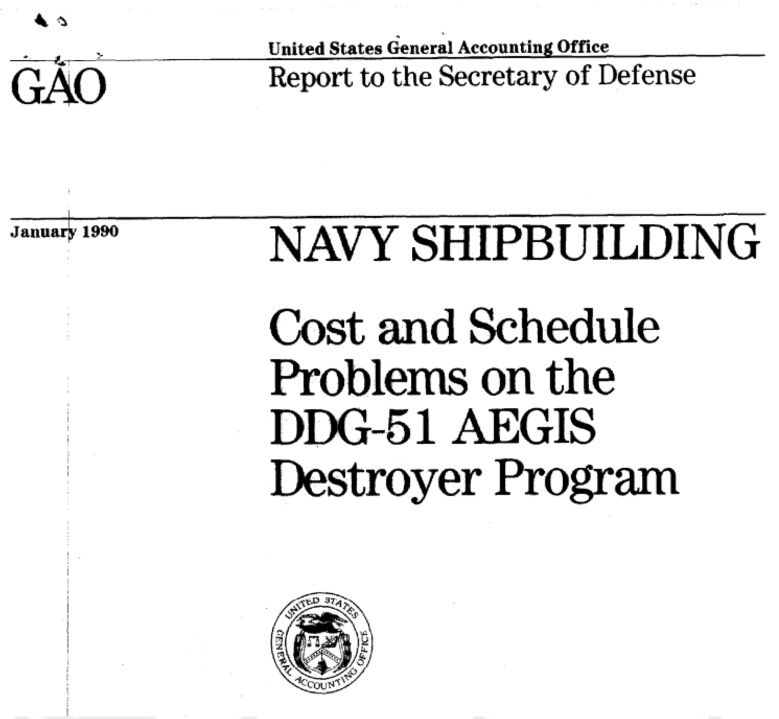
Bath Iron Works planned to prepare production drawings using computer-aided design, but major problems arose. The computer equipment did not have adequate data storage capacity needed to design a complex warship. Design delays were also due to Navy changes in ship requirements, late government-furnished design data for the reduction gear, and difficulties with several developmental systems. As of November 1989, Bath Iron Works and Navy representatives believed that design problems had been resolved and production drawings were essentially complete. GAO believes that the installation and integration of the ship systems, which still has to be done, could surface additional design or performance problems.

Construction Problems

Design and other problems contributed to two revisions to the ship's scheduled delivery, totaling 17 months. The last revision to the delivery schedule was made in February 1988. The ship, originally scheduled to be completed in September 1989, is currently scheduled for delivery in February 1991. Bath Iron Works is accelerating construction to meet this date.

Bath Iron Works launched the lead ship in September 1989. According to Bath Iron Works representatives, the ship was more than 50 percent complete in October 1989. However, to complete the ship requires incorporating and integrating the AEGIS combat system and demonstrating that other systems, such as the collective protection system, work as designed.

In January 1989, the Navy modified the DDG-52 contract to provide for better helicopter support capabilities, which rescheduled the delivery date by 8 months. Also, the Navy has approved a proposal by Bath Iron Works to reschedule the DDG-53 construction schedule. The 7-month rescheduling will allow Bath Iron Works to more efficiently schedule its work on other ships it is building for the government. These ships will be delivered earlier than expected.



http://www.gao.gov/assets/150/148526.pdf

Cost Modeling (Research and Data Analysis)

Cost information on Communications was obtained as shown here…

Items	*Quantity*	*Min Unit Cost*	*Aveg Unit Cost*	*Max Unit Cost*	*Total Cost ($M)*
	5.00	*967.39*	*1,248.62*	*1,897.64*	*1,248.62*
Interior Communications					
AN/STC-2(V) Integrated Voice Communications System (IVCS), IC	1	0.0064	0.008	0.0096	0.01
AN/USQ-82(V) Fiber Optic Data Multiplex System (FODMS)	1	0.784	0.98	1.176	0.98
Exterior Communications:					
High Frequency (HF) radio group AN/URC-131A(V)	2	0.012	0.015	0.018	0.03
Very High Frequency (VHF) transmit and receive, 30-162 MHz:					
- AN/GRC-211; two transceivers for non-secure voice.					
- AN/VRC-46A; two FM transceivers for secure voice.					
- AN/URC-139; one transceiver for bridge-to-bridge communications.	3	0.008	0.01	0.012	0.03
Ultra High Frequency (UHF) transmit and receive, 220-400 MHz:					
- AN/GRC-171B(V)4; two transceivers for Link 4A.					
- AN/WSC-3(V)7, 11; sixteen transceivers.	2	0.044	0.062	0.08	0.12
Satellite Communications (SATCOM) transmit and/or receive:					
- AN/USQ-122A(V); one receiver for fleet broadcast.					
- AN/WSC-3(V)15; two transceivers for digital exchange system.	2	0.04	0.057	0.074	0.11
38(V)2; one transceiver.	1	1.009	1.262	1.514	1.26
Infrared transmit and receive:					
- AN/SAT-2A; one IR transmitter.					
Landline terminations, transmit and/or receive:					
- Single channel Disable Communications (DC) secure Teletypewriter (TTY).					
- Telephone.					
Special communications channel:					
- ON-143(V)6/USQ: Officer in Tactical Command Information Exchange Subsystem(OTCIXS).					
- ON-143(V)6/USQ: Tactical Data Information Exchange System (TADIXS).					
- TADIXS-B/CTT-H3.					
- AN/SYQ-7A(V): Naval Modular Automated Communication System/Common User Digital Exchange System (NAVMACS/CUDIXS).					
- AN/UYQ-62(V)2, Command and Control Processor (C2P).	7	0.04	0.056	0.072	0.39
Underwater Communications:					
- AN/WQC-2A sonar communications set.					
- AN/WQC-6 sonar communications set.	2	4.133	5.166	6.199	10.33

Project Tasks (ICT and Navigation Systems)

Information, Communication & Technology

Planning → Procurement

Planning → Engineering and Navy Requirements → Procurement

Interior Communications
- AN/STC-2(V) Integrated Voice Communications System (IVCS), IC switchboards.
- AN/USQ-82(V) Fiber Optic Data Multiplex System (FODMS).

Exterior Communications
- High Frequency (HF) radio group AN/URC-131A(V).
- "Very High Frequency (VHF) transmit and receive, 30-162 MHz:- AN/GRC-211; two transceivers for nonsecure voice.- AN/VRC-46A; two FM transceivers for secure voice.- AN/URC-139; one transceiver for bridge-to-bridge communications."
- "Ultra High Frequency (UHF) transmit and receive, 220-400 MHz:- AN/GRC-171B(V)4; two transceivers for Link 4A.- AN/WSC-3(V)7, 11; sixteen transceivers."
- "Satellite Communications (SATCOM) transmit and/or receive:- AN/USQ-122A(V); one receiver for fleet broadcast.- AN/WSC-3(V)15; two transceivers for digital exchange system." / Extremely High Frequency (EHF) SATCOM transmit and receive:- AN/USC-38(V)2; one transceiver. / "Infrared transmit and receive:- AN/SAT-2A; one IR transmitter." / "Landline terminations, transmit and/or receive:- Single channel Disable Communications (DC) secure Teletypewriter (TTY).- Telephone."

Special Communications Channel
- "ON-143(V)6/USQ: Officer in Tactical Command Information Exchange Subsystem(OTCIXS).- ON-143(V)6/USQ: Tactical Data Information Exchange System (TADIXS).- TADIXS-B/CTT-H3.- AN/SYQ-7A(V): Naval Modular Automated Communication System/Common User Digital Exchange System (NAVMACS/CUDIXS).- AN/UYQ-62(V)2, Command and Control Processor (C2P).- AN/USQ-118(V)1, Link 11.- AN/URC-107(V): Joint Tactical Information Distribution System (JTIDS), Link 16."

Underwater Communications
- AN/WQC-2A sonar communications set.- AN/WQC-6 sonar communications set.
- Computer-Aided Systems (Hardware and Software).

http://www.seaforces.org/usnships/ddg/Arleigh-Burke-class.htm

Navigational Equipment

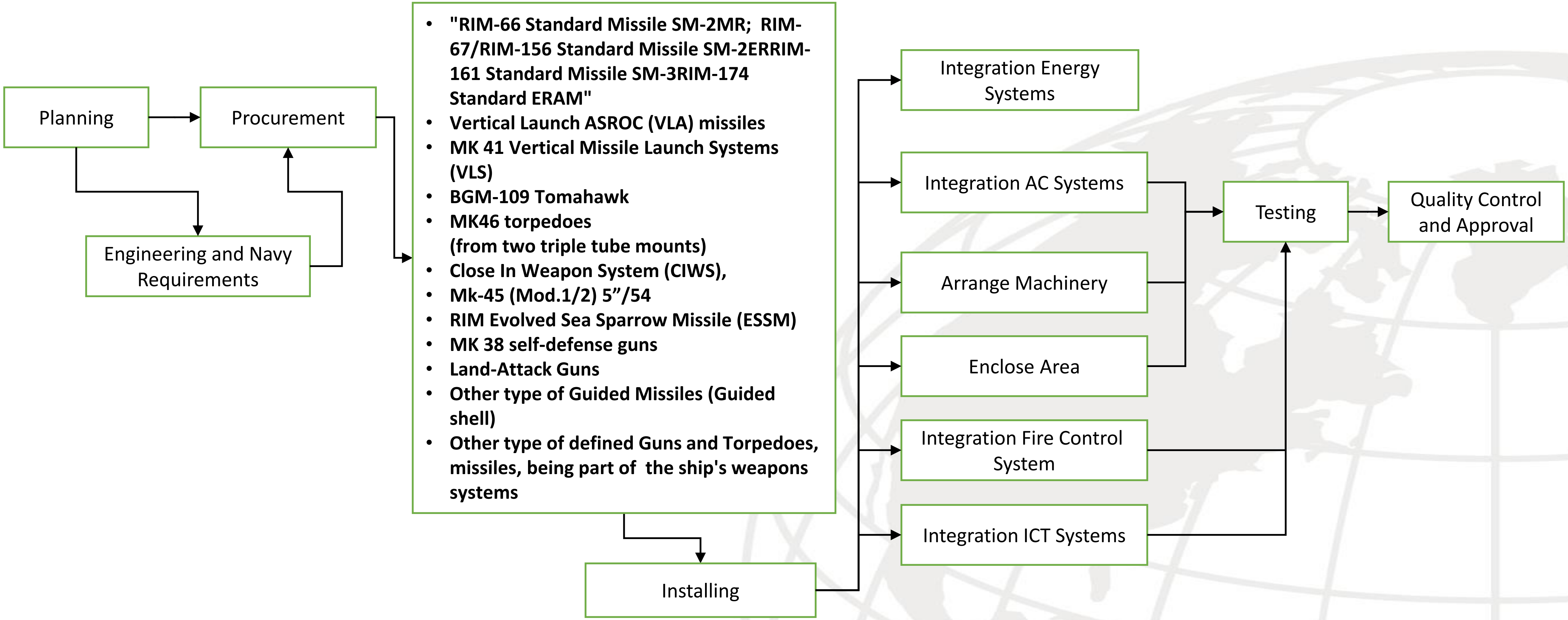
- AN/WSN-5 Inertial Navigation System; AN/WRN-6; ANISRN-25 (V); MK 4 MOD 2 Underwater Log; MK 6 MOD 4D Digital Dead Reckoning Tracer.
- AN/URN-25 TACAN; AN/SPS-64 (V) 9 I Band Radar.
- Navy Standard No. 3 Magnetic Compass; Chronometer Size 85; Flux Compass.

Installing
- Integration AC Systems
- Integration Energy Systems
- Arrange Machinery
- Enclose Area
- Integration Fire Control System
- Integration ICT System

Testing

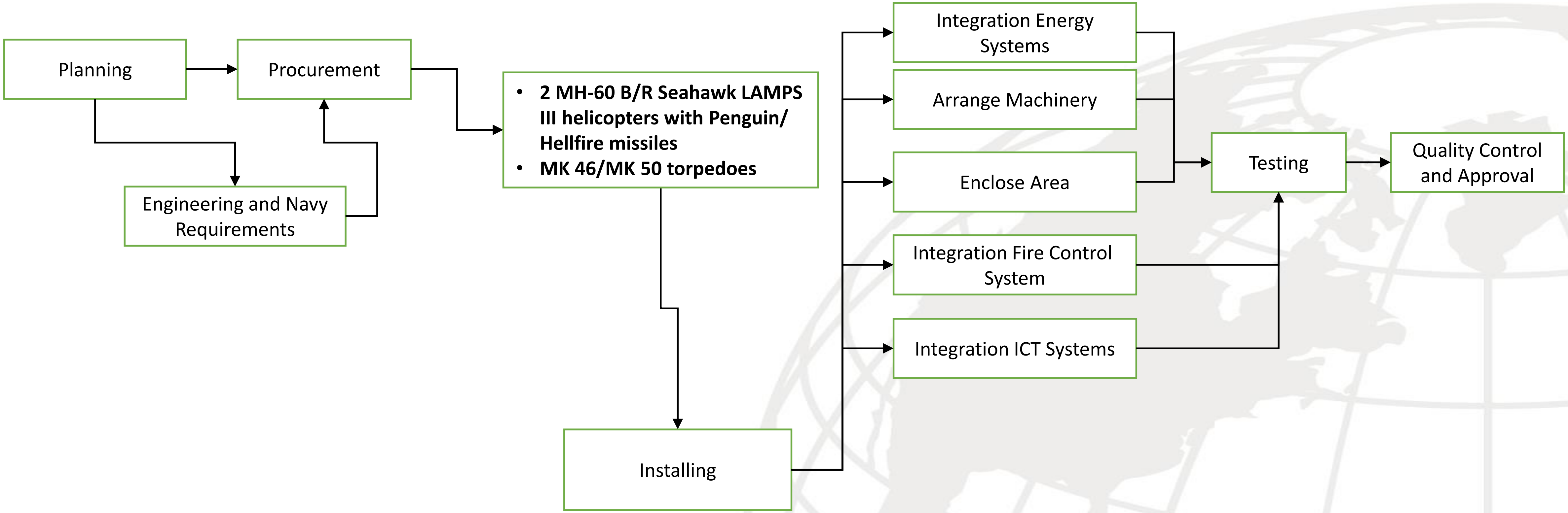
Quality Control and Approval

Project Tasks (Armament Systems)



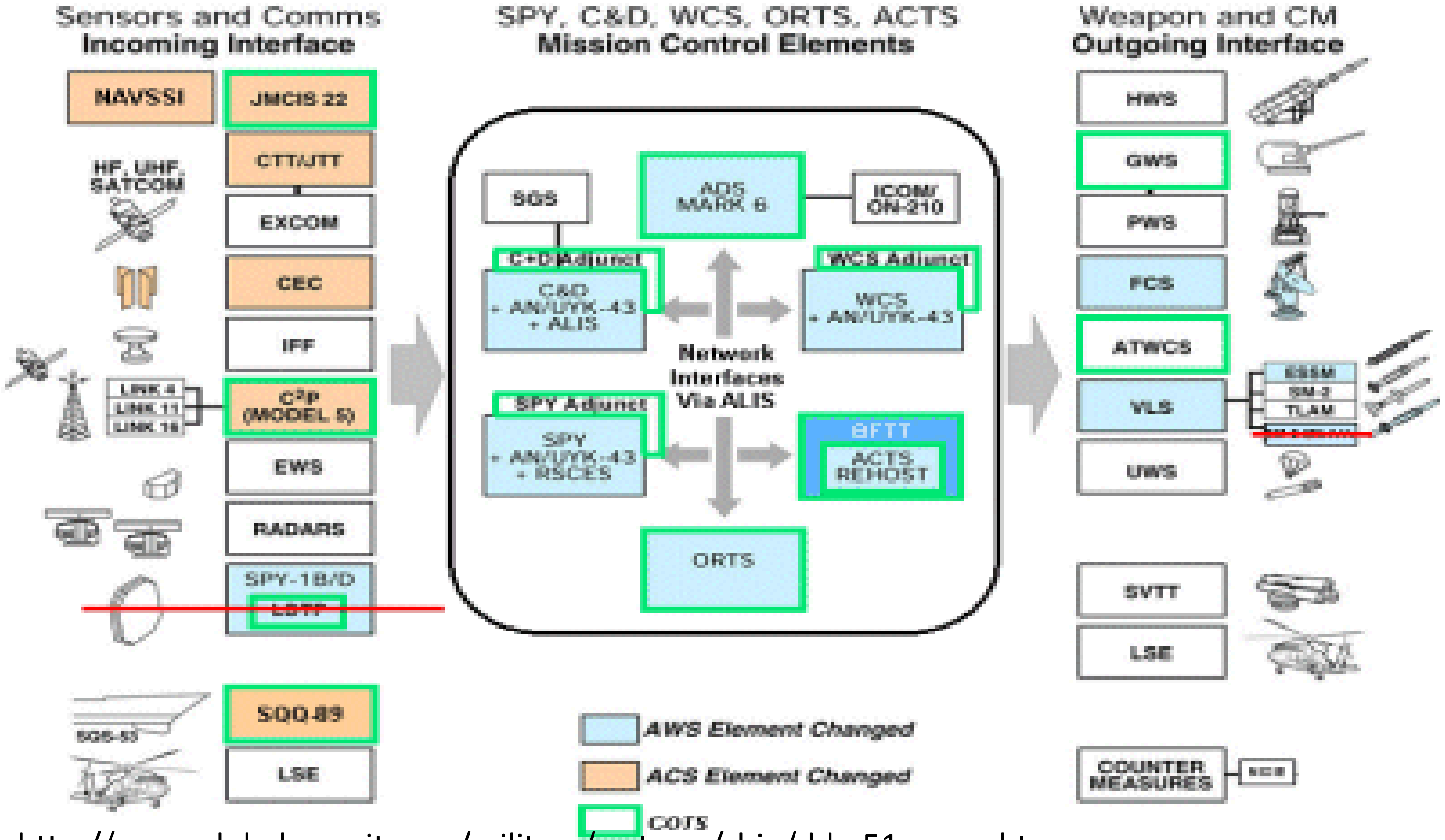
Sources:
http://www.seaforces.org/usnships/ddg/Arleigh-Burke-class.htm
http://www.globalsecurity.org/military/systems/ship/ddg-51-specs.htm

Project Tasks (Aircraft)



Current Aircraft and Armament Distribution

Flight I	Flight IIA
None. LAMPS III electronics installed on landing deck for coordinated DDG 51/helo ASW operations	Two multi-purpose Light Airborne Multipurpose System LAMPS MK III helicopters



http://www.globalsecurity.org/military/systems/ship/ddg-51-specs.htm

Missiles:

Flight I: 90 cell Mk 41 Vertical Launching System (VLS)
Flights II and IIA: 96 cell Mk 41 VLS
Tomahawk cruise missile
RIM-66M Standard medium range SAM (has an ASUW mode)[citation needed]
RIM-161 Standard Ballistic missile defense missile for Aegis BMD (15 ships as of March 2009[6])
RIM-162 ESSM (4 per cell) SAM (DDG-79 onward)
RUM-139 Vertical Launch ASROC
RIM-174A Standard ERAM added in 2011
2 × Mk 141 Harpoon Missile Launcher SSM (not in Flight IIA units)[7]

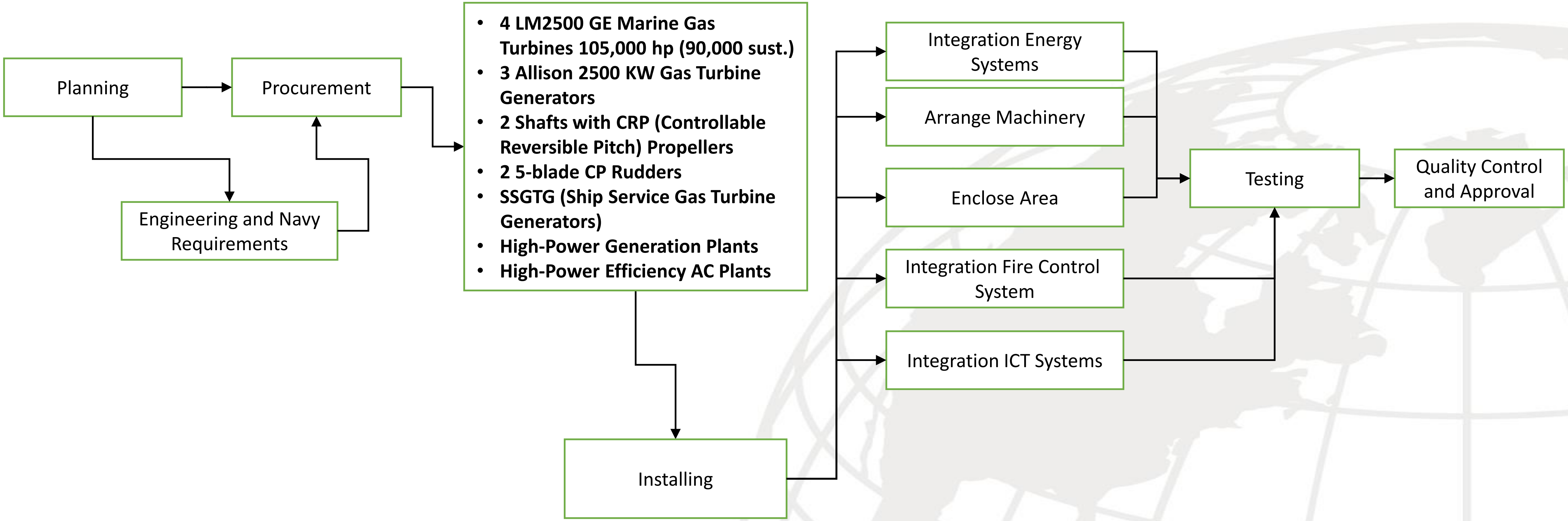
Guns:

1 × 5-inch (127-mm)/54 Mk-45 Mod 1/2 (lightweight gun) (DDG-51 to -80); or
1 × 5-inch (127-mm)/62 Mk-45 mod 4 (lightweight gun) (DDG-81 onwards)
2 × (DDG-51 to -84); or 1 × (DDG-85 onwards) 20 mm Phalanx CIWS
2 × 25 mm M242 Bushmaster cannons

Torpedoes:

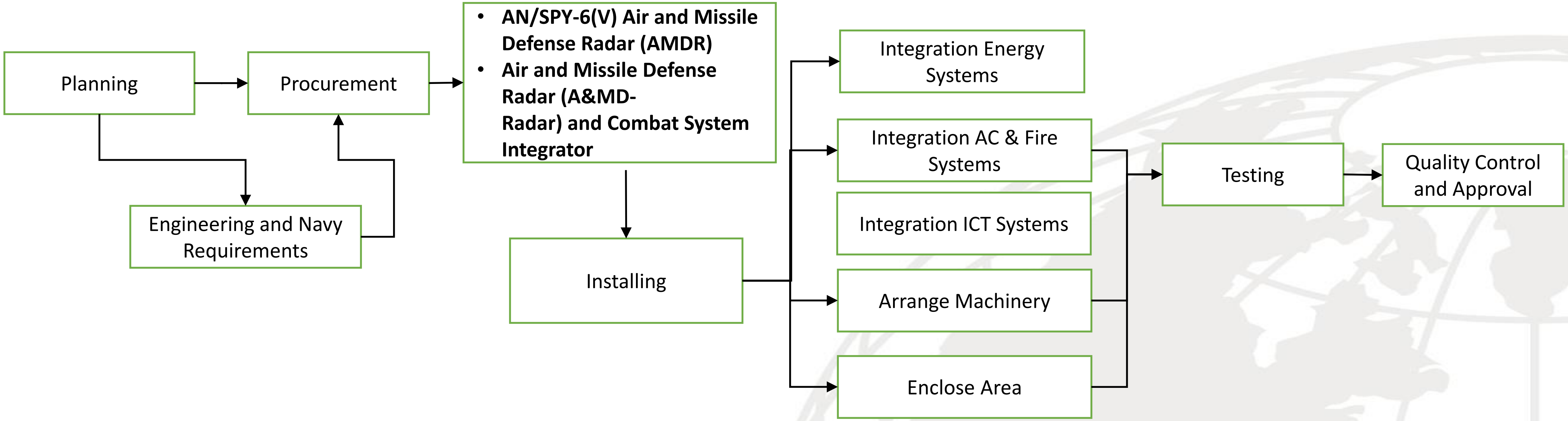
2 × Mark 32 triple torpedo tubes (six Mk-46 or Mk-50 torpedoes, Mk-54 in the near future)

Project Tasks (Energy Systems)



Propulsion is supported by 4 General Electric LM2500 gas turbines each generating 26,500 hp (19,800 kW);[4] coupled to two shafts, each driving a five-bladed reversible controllable-pitch propeller

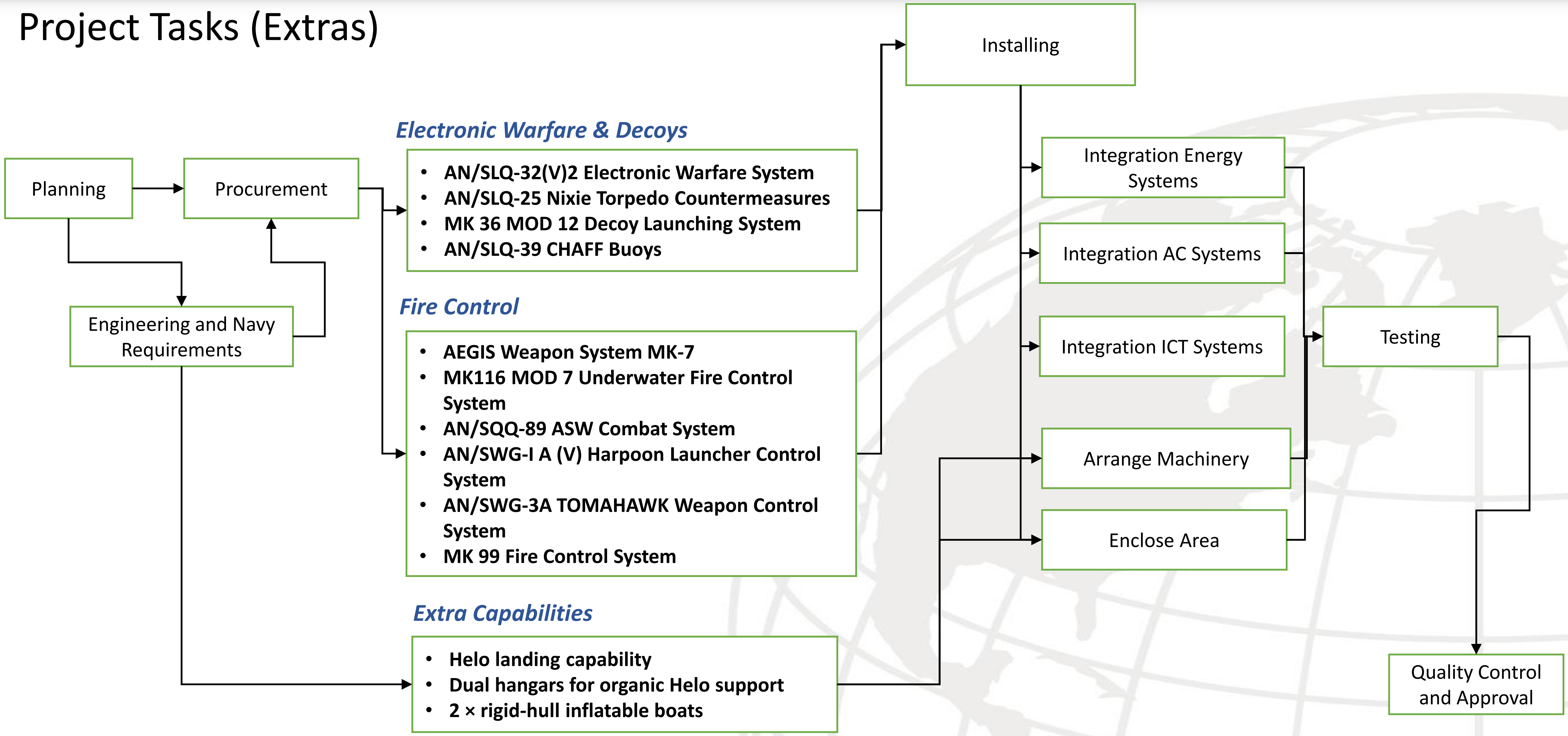
Project Tasks (Radar Systems)



The program completed Technology Development (TD) contracts in September 2012 and released a Request for Proposals for the E&MD Phase in June 2012. The AMDR program achieved Milestone B in September 2013 and received a signed Acquisition Decision Memorandum on October 4, 2013. After a full and open competition, an Engineering and Manufacturing Development (E&MD) phase contract was awarded to Raytheon on October 10, 2013. Raytheon was awarded a $385,742,176 cost-plus-incentive-fee contract for the engineering and modeling development phase design, development, integration, test, and delivery of Air and Missile Defense S-Band Radar (AMDR-S) and Radar Suite Controller (RSC).

http://www.globalsecurity.org/military/systems/ship/systems/amdr.htm

Project Tasks (Extras)



Project Tasks (Support)

Support Services

Information Systems → Planning and Project Mgmt. → Contract Admin → Quality Control → Security Health and Assurance → Yard Services

Yard Administration

Ship Yard Admin. → Cost Controlling → Finance → Marketing

DDG-51-POST Building Specifications

Departments	Administration Combat Systems Engineering Navigation Operations Supply Weapons
Unit Operating Cost Annual Average	$20,000,000 [source: [FY1996 VAMOSC]

http://www.globalsecurity.org/military/systems/ship/ddg-51-specs.htm

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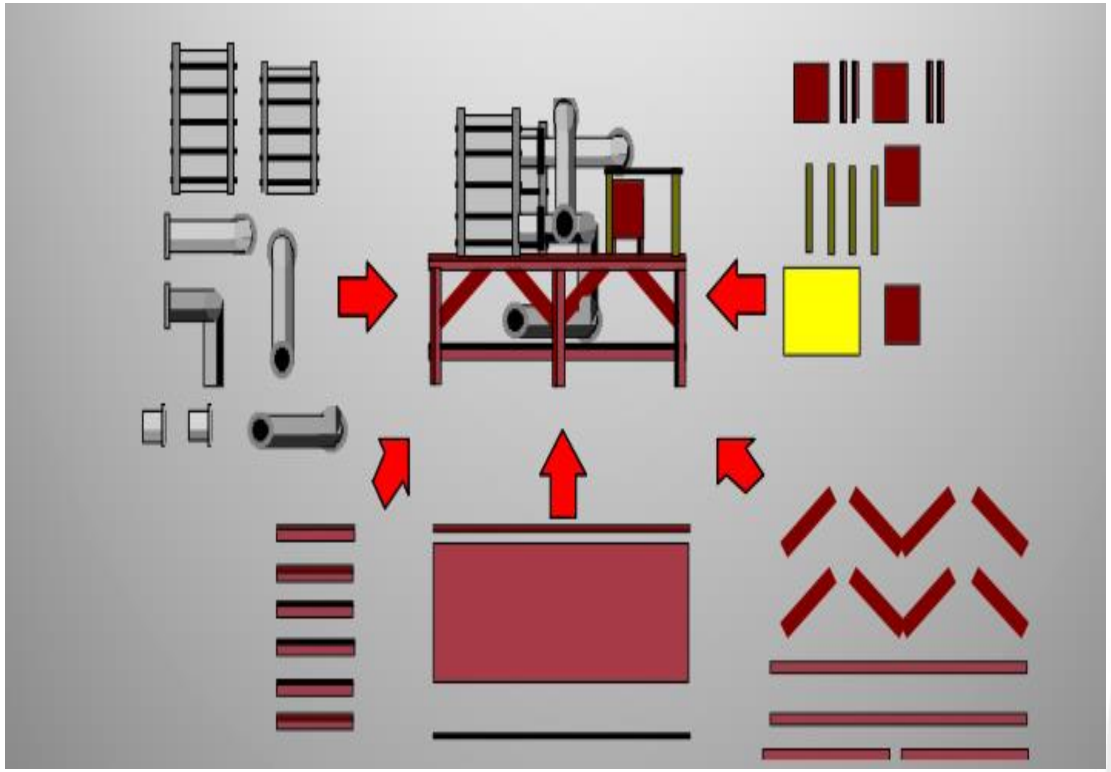
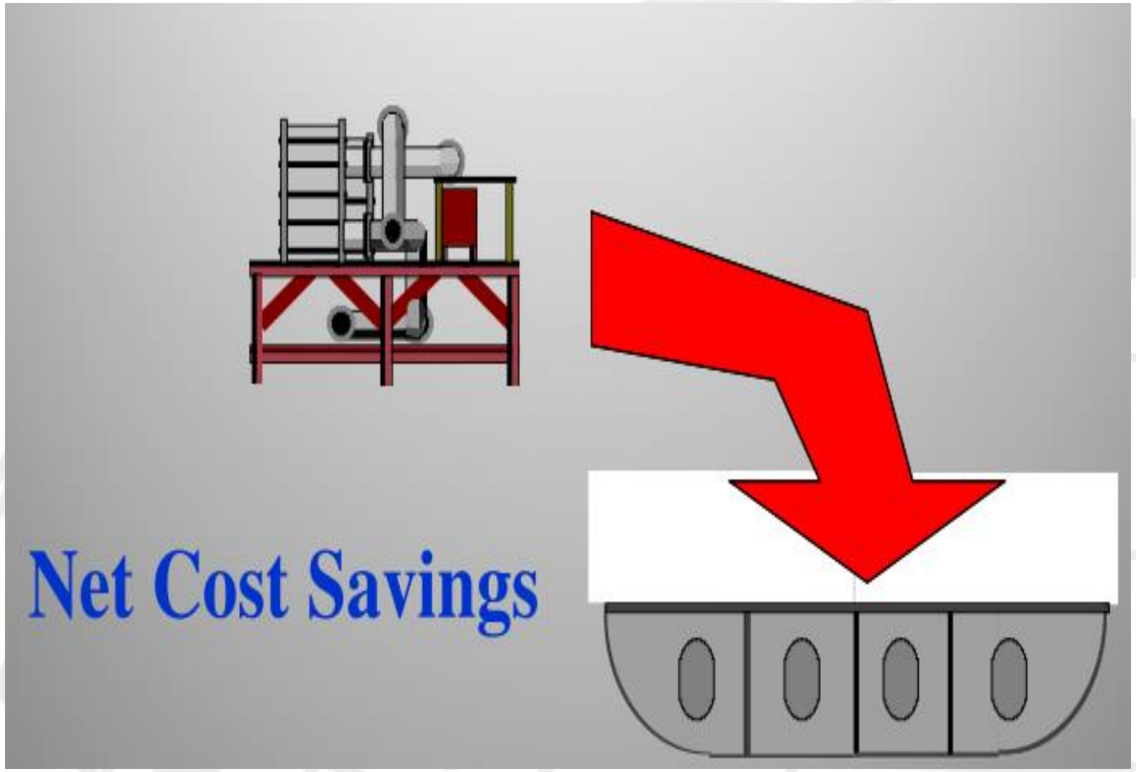
APPENDIX 2
Shipbuilding Concepts and Design

Monterey, California
WWW.NPS.EDU

Building outfit module in shop & installing outfit module on block



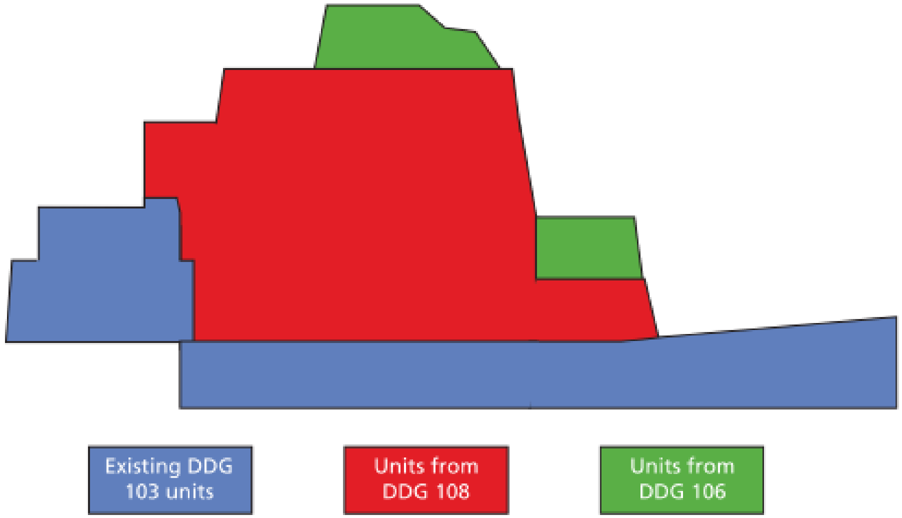


Erection process - Assembly & Wet Berth

The first grand blocks of the future USS John Finn (DDG 113) are erected on the building ways at the Ingalls Shipbuilding yard in Pascagoula, Miss. Huntington Ingalls Industries photo.

Shared Modular Build of Warships: How a Shared Build Can Support Future Shipbuilding

Figure A.2
DDG-51 Sections



SOURCE: Kenyon (2009, slide 3). Used with permission.
RAND TR852-A.2

https://news.usni.org/2015/11/12/navyindustryworkingthroughddg51flightiiidetaildesigndraftrfpforshipconstructionreleased

Internal Communications (Ethernet Capabilities)

Gigabit Ethernet Data Multiplex System

Status: Pending Implementation

PROBLEM / OBJECTIVE

For over 20 years, the most expensive component in the production of the CV-4414/USQ-82(V), the input/output unit (IOU), has been the flexible circuit assemblies. The cost of these assemblies is over 30 percent of the total cost of the unit. With the recent addition of gigabit Ethernet interface capability to the IOU, the flex cable assemblies must be updated to support the higher signaling rates. While the new gigabit Ethernet modules can operate at a 1,000 Mbit/sec link speed, the existing flexible circuits introduce an impedance discontinuity interface that limits the performance to a 100 Mbit/sec link speed. The continual upgrade of the Navy's equipment to Internet Protocol (IP) based interfaces is driving the need for the higher data rate interfaces to the GEDMS IOU equipment. Hence, there is an urgent need to develop a cost effective and producible IOU flex cable solution that meets the performance requirements. The objective is to develop high yielding design rules for flexible circuits that will accommodate the presently used 42-pin M28840 connector that provides an interface to the external user systems. The approach will utilize reproducible and transportable processes, as well as reducing the amount of touch labor in the manufacturing process.

ACCOMPLISHEMENTS / PAYOFF

Process Improvements

The introduction of these IOU flex cable solutions will improve performance by providing higher link speeds, increase producibility, increase reliability, lower acquisition costs, and lower total ownership costs by reducing touch labor in the manufacturing process. A savings of $120K will be realized per hull and a total savings of $4.95M when the modernizations of all the current DDG Flight I platforms using DMS and the expected modernizations of the Flight II hulls are completed.

High performance IOU flex cable is needed for the third DMS network backbone upgrade - GEDMS

The cost reductions will be realized beginning with the FY14 DDG Modernization ships and new construction DDGs.

This ManTech project leveraged Boeing's investment in manufacturing enhancement work to assemble and package prototypes for performance validation and inclusion in the government's production design package.

The transition point for the project was the successful completion of the prototype rigid-flex circuits test, review and approval of the test results by the GEDMS Program Manager, and the incorporation of the design changes into the design production package.

TIME LINE / MILESTONE

Program Start:	June 2012
Program End:	February 2014

FUNDING

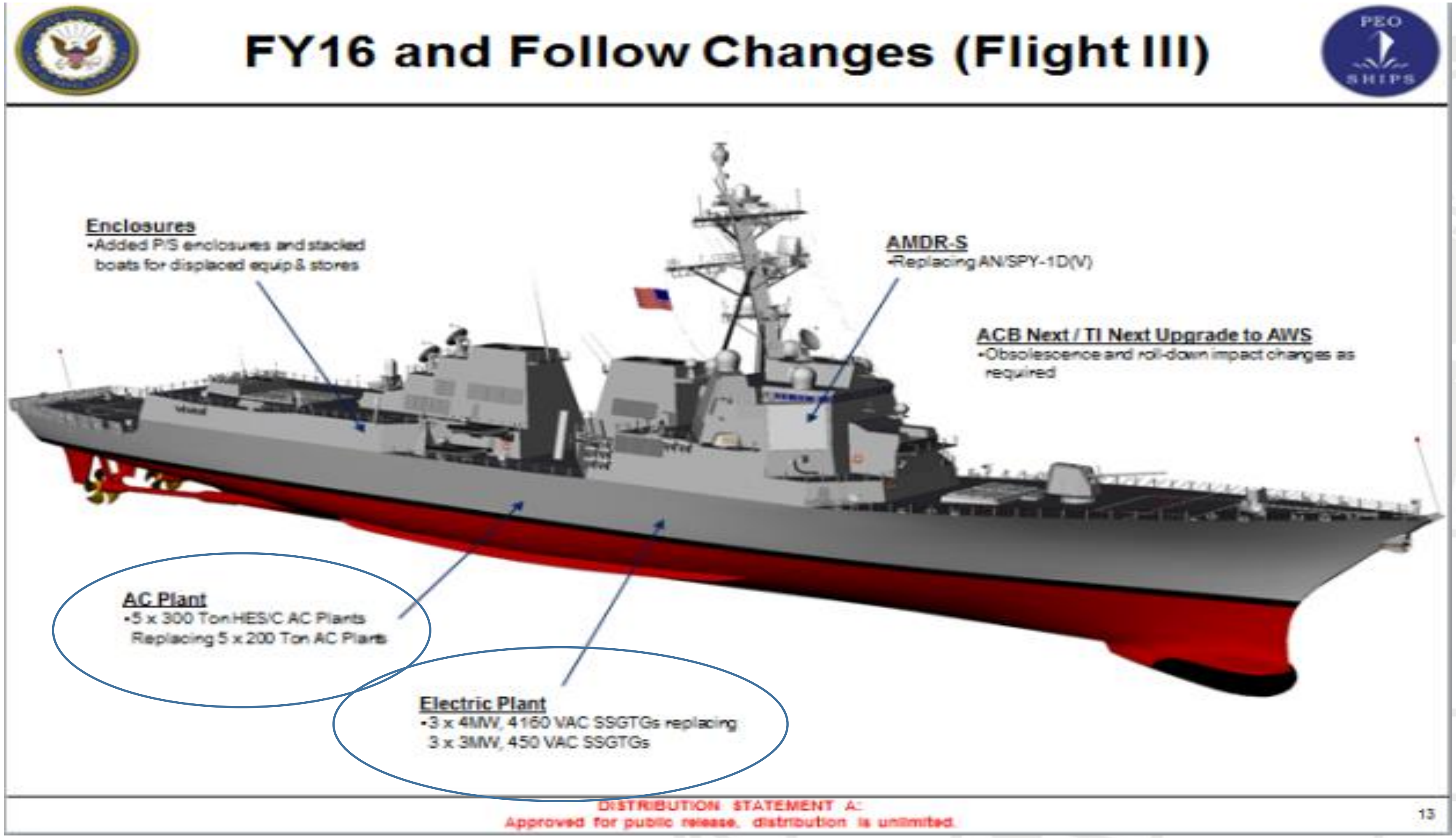
Navy ManTech Investment: $938K

PARTICIPANTS

DDG 51 Program Office – Stakeholder

https://www.dodmantech.com/ManTechPrograms/Files/Navy/Gigabit_Ethernet_Data_Multiplex_System_REV_B_AUG14.pdf

AC & Electric Plant Areas



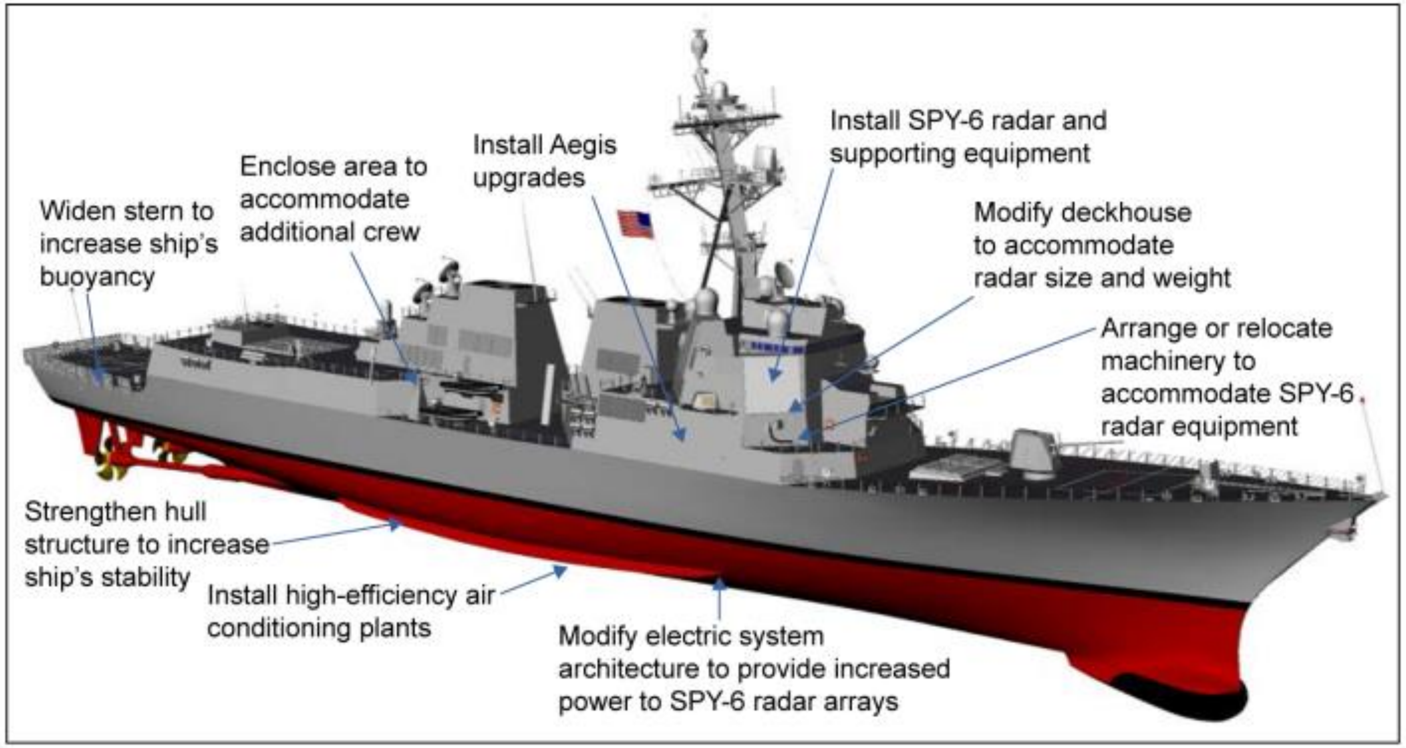
https://news.usni.org/2016/05/01/bath-iron-works-will-build-first-flight-iii-arleigh-burke-ddg

SPY-6 Radar and Combat System Integrator

An artist's conception of a Raytheon's SPY-6 radar. Raytheon Photo

https://news.usni.org/2015/11/12/navyindustryworkingthroughddg51flightiiidetaildesigndraftrfpforshipconstructionreleased

SPY-6 Radar and Design Knowledge



Source: GAO (analysis); Navy (image and data). | GAO-16-613

ARLEIGH BURKE DESTROYERS:

Delaying Procurement of DDG 51 Flight III Ships Would Allow Time to Increase Design Knowledge

GAO-16-613: Published: Aug 4, 2016. Publicly Released: Aug 4, 2016.

What GAO Found

The Air and Missile Defense Radar (AMDR) program's SPY-6 radar is progressing largely as planned, but extensive development and testing remains. Testing of the integrated SPY-6 and full baseline Aegis combat system upgrade—beginning in late 2020—will be crucial for demonstrating readiness to deliver improved air and missile defense capabilities to the first DDG 51 Flight III ship in 2023. After a lengthy debate between the Navy and the Department of Defense's (DOD) Director of Operational Test and Evaluation, the Secretary of Defense directed the Navy to fund unmanned self-defense test ship upgrades for Flight III operational testing, but work remains to finalize a test strategy.

Energy, Radars, and Defense Systems (Integration)

Primary Electronic Warfare System

U.S. Navy Installs AN/SLQ-32(V)6 System On DDG-96 For Operational Testing

U.S. Navy installed the Lockheed Martin SEWIP Block 2 System on DDG-96 for operational testing ove

Lockheed Martin Corporation (LMT - Free Report) has received a contract worth $57 million from the U.S. Navy for upgrading the AN/SLQ-32(V)2 system that is installed on all U.S. aircraft carriers, cruisers, destroyers, and other warships.

http://www.globalsecurity.org/military/systems/ship/ddg-51-specs.htm

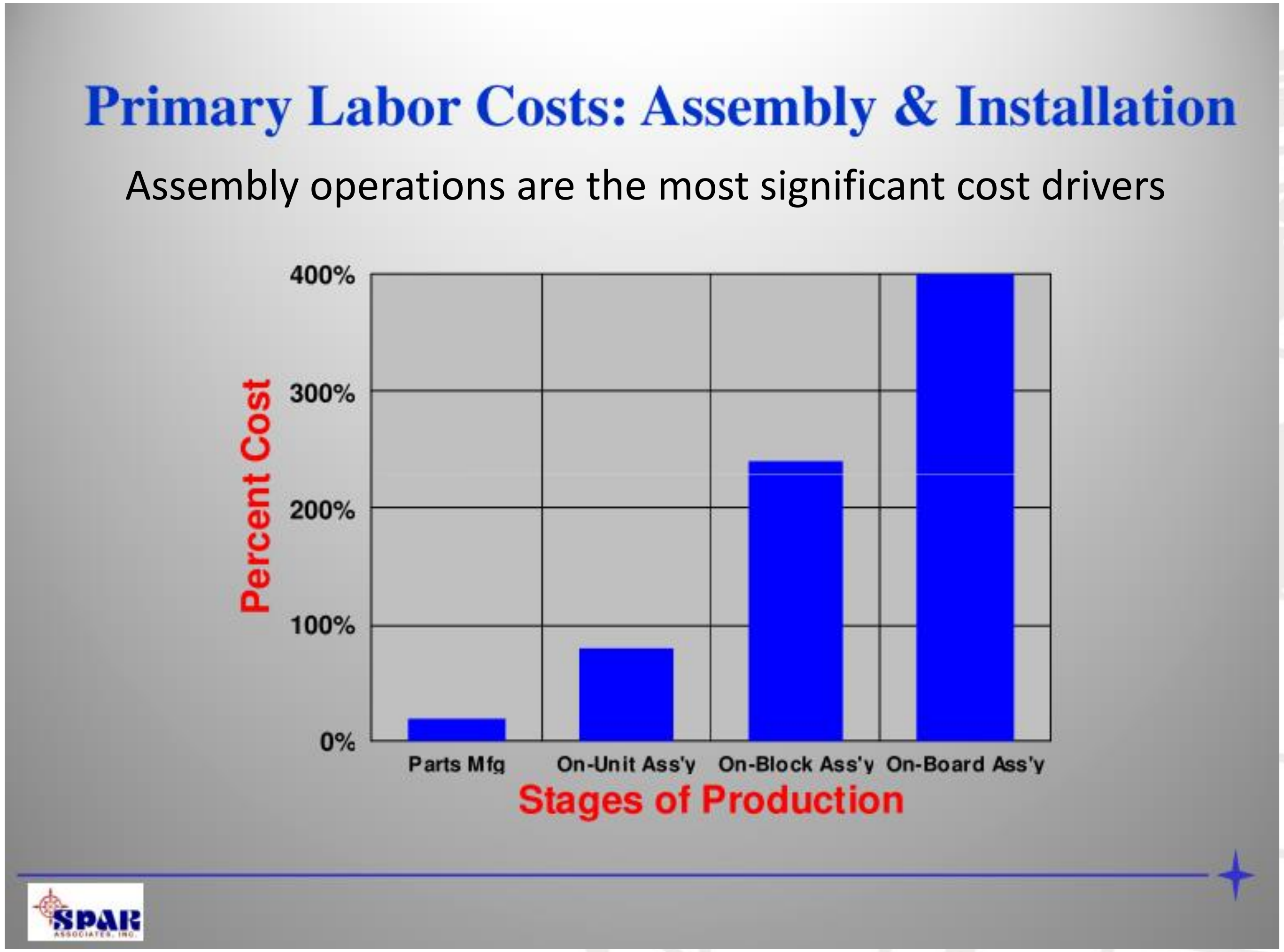
General Criteria for Warship Specifications

DDG-51 Arleigh Burke - Specifications

	Specifications
Power Plant	4 - LM2500 GE Marine Gas Turbines 105,000 shp (90,000 sust.) 3 Allison 2500 KW Gas Turbine Generators 2 Shafts with CRP (Controllable Reversible Pitch) Propellers 2 5-blade CP Rudders
Length	Flight I: 505 feet overall 466 feet (142 meters)waterline Flight IIA: 509.5-513.0 feet overall Flight III:
Beam	Max 66 Feet waterline 59 feet (18 meters)
Navigational Draft	31 feet
Displacement	Flight I: 8,300 tons full load Flight IIA: 9,192-9,648 tons full load Flight III: 10,700 tons
Speed	31 knots (36 mph, 57 kph)
Range	4,400 @ 20 knots

http://www.globalsecurity.org/military/systems/ship/ddg-51-specs.htm

Most Significant Cost Drivers



Project Management Perspectives in Shipbuilding

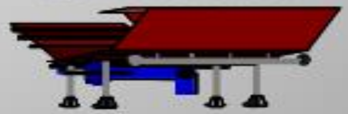
Planning, Integrating & Managing Shipyard Resources

- Engineering
- Purchasing
- Planning
- Parts Manufacturing
- Shipyard facilities
- Sub-Contractors

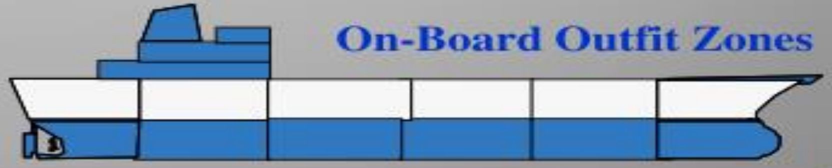
Shipyard Products

Equipment & Outfit System Modules

Pre-Outfitted Hull Block Construction



On-Board Outfit Zones



SPAR ASSOCIATES, INC.

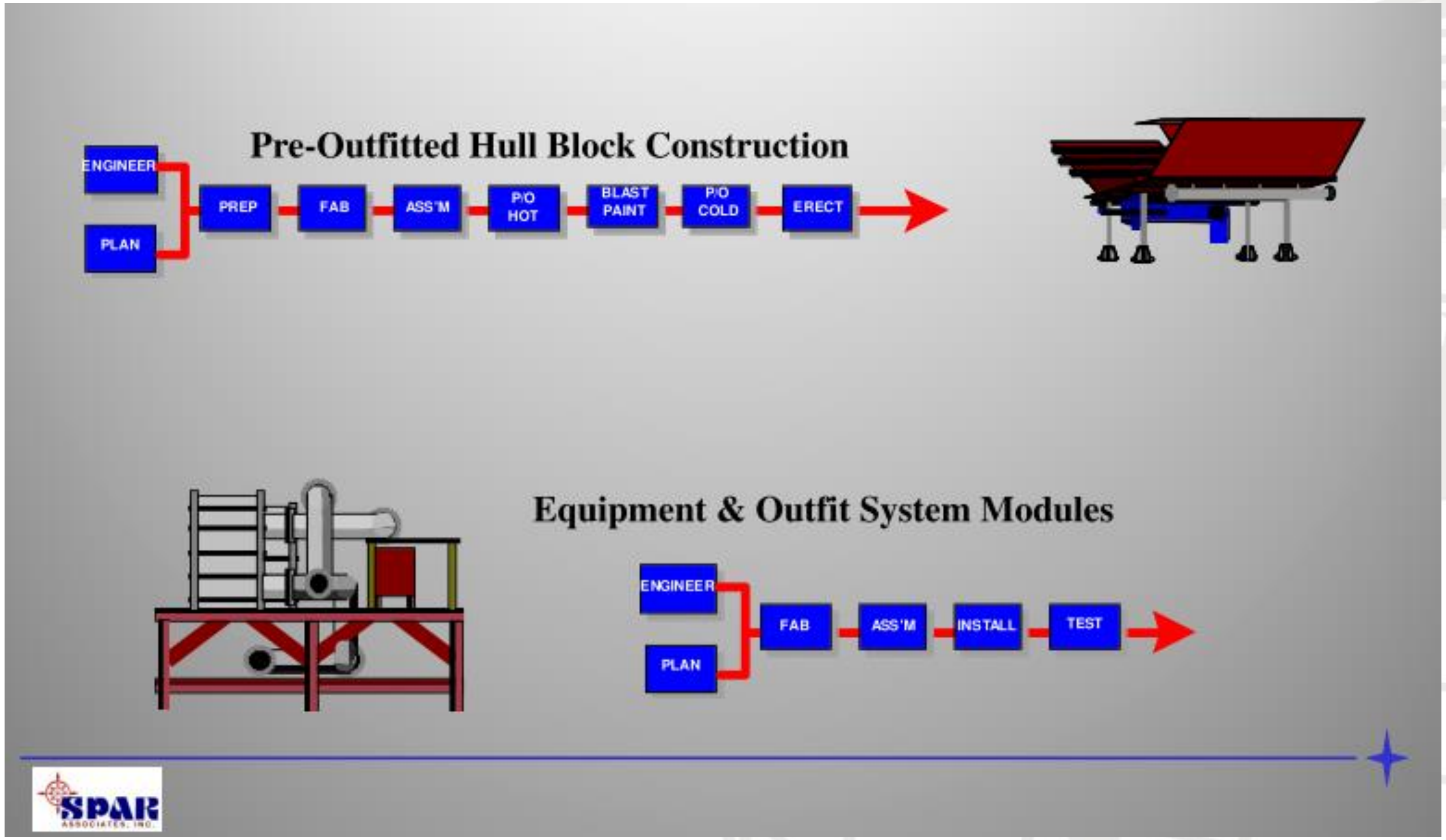
Project Management Perspectives in Shipbuilding

Develop the Build Strategy

- Production Engineering Plan
- Manufacturing & Assembly of Structural Parts Plan
- Manufacturing & Assembly of Outfit Systems Plan
- Hull Block Construction Erection Sequence Plan
- Assembly & Erection of Equipment & Outfit Modules Plan
- On-Board Zone Outfit Plan
- Tests & Trials Plan

SPAR ASSOCIATES, INC.

Construction and Integration



Features of DDG Destroyers (i.e., 51 – 1000)

United States Navy
Fact File

DESTROYERS - DDG

Description
DDG 51 and DDG 1000 destroyers are warships that provide multi-mission offensive and defensive capabilities. Destroyers can operate independently or as part of carrier strike groups, surface action groups, amphibious ready groups, and underway replenishment groups.

Features
Guided-missile destroyers are multi-mission surface combatants capable of conducting Anti-Air Warfare (AAW), Anti-Submarine Warfare (ASW), and Anti-Surface Warfare (ASUW). The destroyer's armament has greatly expanded the role of the ship in strike warfare utilizing the MK-41 Vertical Launch System (VLS).

DDG 51 Class Features:
- AEGIS Weapons System (AWS) including SPY-1 Radar, 96 cell MK 41 VLS, MK 99 Fire Control System
- AN/SQQ-89 Sonar
- MK 45 5� Gun for ASuW, AAW), and land attack (NSFS) targets
- 25mm CIWS and MK 38 self-defense guns
- SLQ-32 or SEWIP Electronics warfare system
- Helo landing capability (DDG 51-78); Dual Hangars for organic Helo support (DDG 79 and follow)
- Four Gas Turbine Engines driving twin controllable propellers
- Three SSGTG (Ship Service Gas Turbine Generators)
- Robust, redundant, and survivable design with low signature requirements

Characteristics of DDG Destroyers (i.e., 51 – 1000)

United States Navy
Fact File

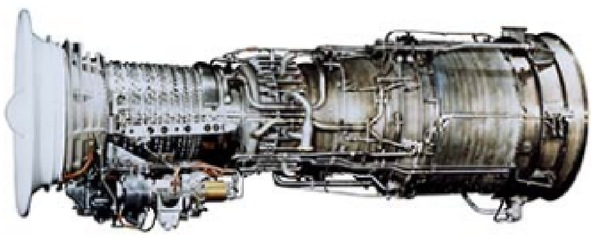
DESTROYERS - DDG

Description
DDG 51 and DDG 1000 destroyers are warships that provide multi-mission offensive and defensive capabilities. Destroyers can operate independently or as part of carrier strike groups, surface action groups, amphibious ready groups, and underway replenishment groups.

General Characteristics, Arleigh Burke class
Builder: Bath Iron Works, Huntington Ingalls Industries
SPY-1 Radar and Combat System Integrator: Lockheed-Martin
Date Deployed: July 4, 1991 (USS Arleigh Burke (DDg 51)
Propulsion: Four General Electric LM 2500-30 gas turbines; two shafts, 100,000 total shaft horsepower
Length: Flights I and II (DDG 51-78): 505 feet (153.92 meters); Flight IIA (DDG 79 AF): 509 1/2 feet (155.29 meters)
Beam: 59 feet (18 meters)
Displacement: 8,230 - 9,700 Ltons
Speed: In excess of 30 knots
Crew: 329 Total (32 Officer, 27 CPO, 270 Enlisted)
Armament: Standard Missile (SM-2MR); Vertical Launch ASROC (VLA) missiles; Tomahawk; six MK-46 torpedoes (from two triple tube mounts); Close In Weapon System (CIWS), 5-in. MK 45 Gun, Evolved Sea Sparrow Missile (ESSM)
Aircraft: Two LAMPS MK III MH-60 B/R helicopters with Penguin/Hellfire missiles and MK 46/MK 50 torpedoes

Characteristics: General Electric LM2500 Gas Turbines

Models



LM2500

The 33,600-shp LM2500 is GE's most popular marine gas turbine, powering more than 400 ships in 33 world navies.

Download Data Sheet

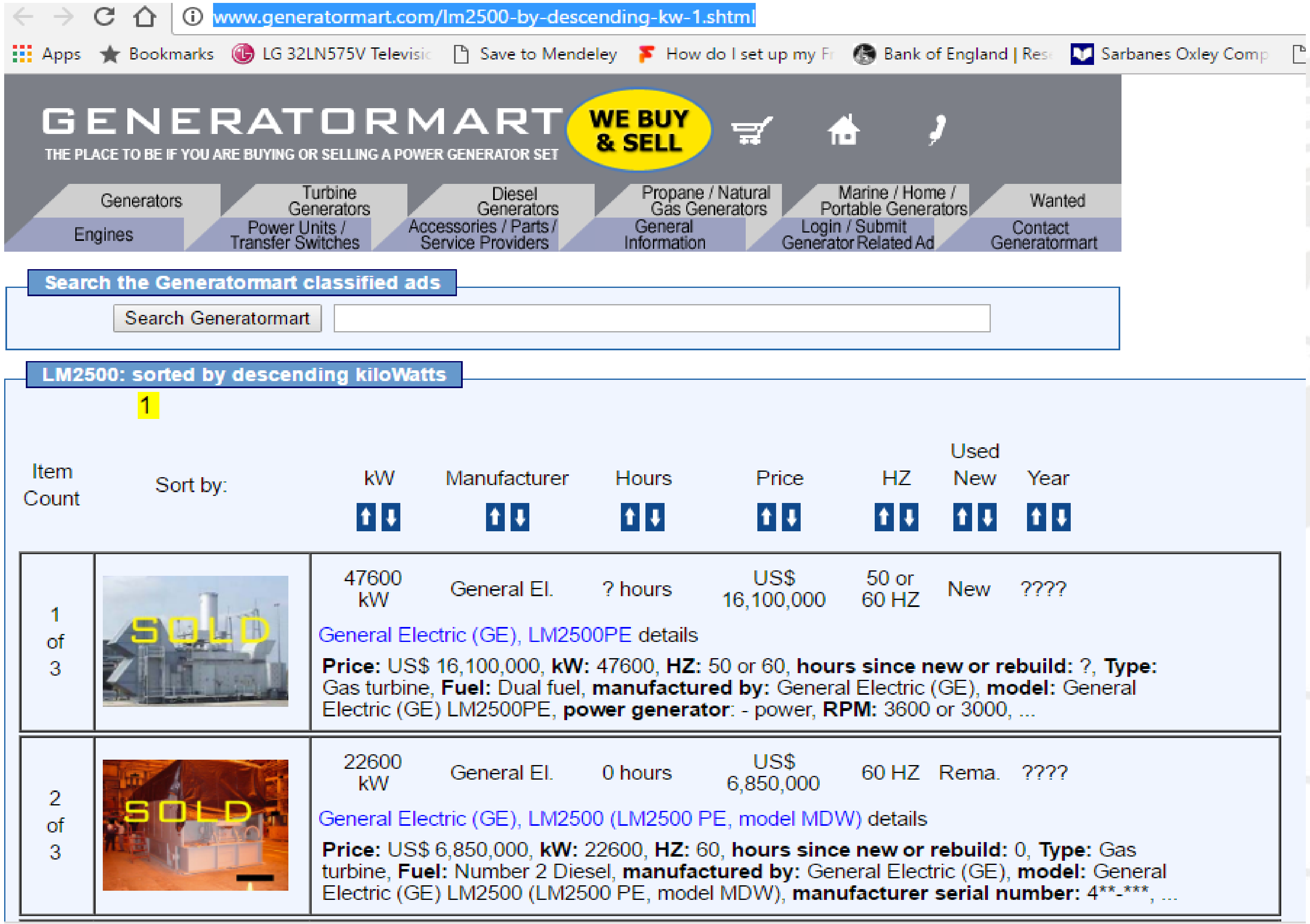
F125-GE Case History **USCG Case History**

USN LCS-GE Case History

Technical

Output	33,600 shp (25,060 kW)
SFC	.373 lb/shp-hr (227 g/kW-hr)
Heat rate	6,860 Btu/shp-hr 9,200 Btu/kWs-hr 9,705 kJ/kWs-hr
Exhaust gas flow	155 lb/sec (70.5 kg/sec)
Exhaust gas temperature	1,051°F (566°C)
Power turbine speed	3600 rpm

Characteristics: General Electric LM2500 Gas Turbines (Cost)



www.generatormart.com/lm2500-by-descending-kw-1.shtml

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Engines | Power Units / Transfer Switches | Accessories / Parts / Service Providers | General Information | Login / Submit Generator Related Ad | Contact Generatormart

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Search Generatormart

LM2500: sorted by descending kiloWatts

1

Item Count	Sort by:	kW	Manufacturer	Hours	Price	HZ	Used New	Year
1 of 3	SOLD	47600 kW	General El.	? hours	US$ 16,100,000	50 or 60 HZ	New	????
2 of 3	SOLD	22600 kW	General El.	0 hours	US$ 6,850,000	60 HZ	Rema.	????

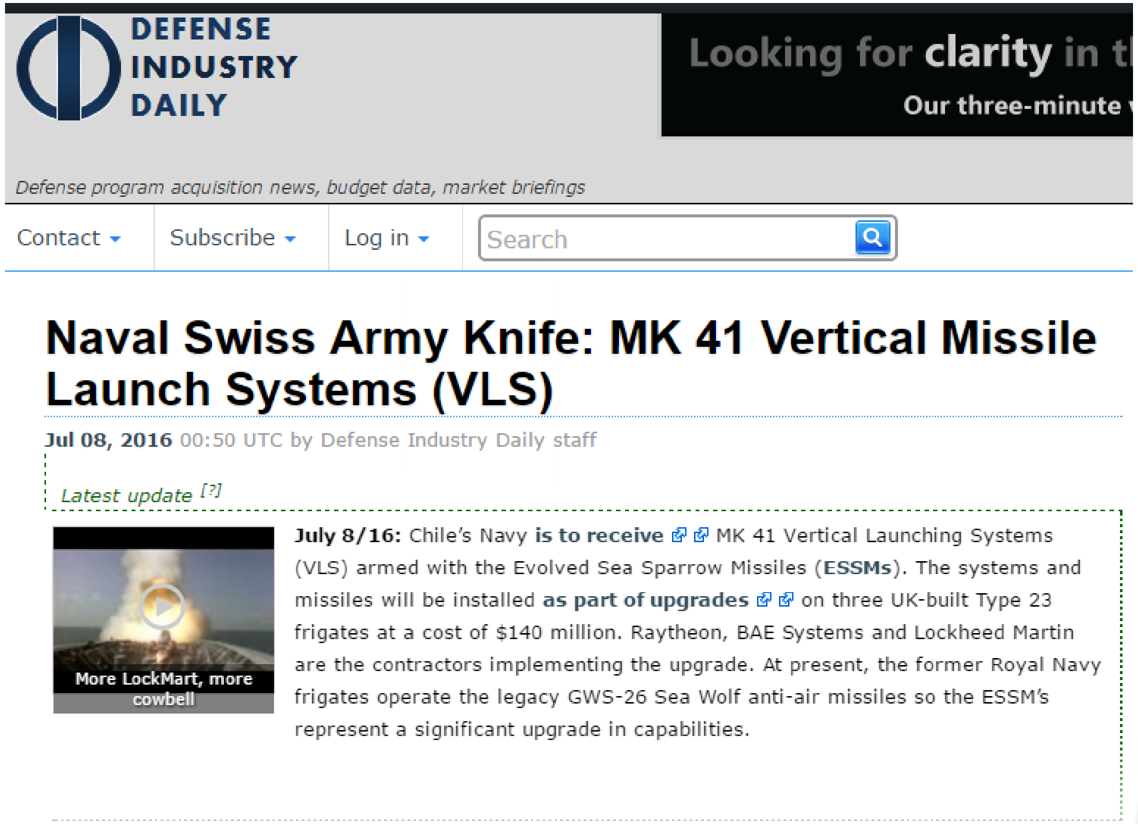
General Electric (GE), LM2500PE details

Price: US$ 16,100,000, **kW:** 47600, **HZ:** 50 or 60, **hours since new or rebuild:** ?, **Type:** Gas turbine, **Fuel:** Dual fuel, **manufactured by:** General Electric (GE), **model:** General Electric (GE) LM2500PE, **power generator**: - power, **RPM:** 3600 or 3000, ...

General Electric (GE), LM2500 (LM2500 PE, model MDW) details

Price: US$ 6,850,000, **kW:** 22600, **HZ:** 60, **hours since new or rebuild:** 0, **Type:** Gas turbine, **Fuel:** Number 2 Diesel, **manufactured by:** General Electric (GE), **model:** General Electric (GE) LM2500 (LM2500 PE, model MDW), **manufacturer serial number:** 4**-***, ...

Vertical Launch Systems (VLS)



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Naval Swiss Army Knife: MK 41 Vertical Missile Launch Systems (VLS)

Jul 08, 2016 00:50 UTC by Defense Industry Daily staff

Latest update [?]

More LockMart, more cowbell

July 8/16: Chile's Navy **is to receive** MK 41 Vertical Launching Systems (VLS) armed with the Evolved Sea Sparrow Missiles (**ESSMs**). The systems and missiles will be installed **as part of upgrades** on three UK-built Type 23 frigates at a cost of $140 million. Raytheon, BAE Systems and Lockheed Martin are the contractors implementing the upgrade. At present, the former Royal Navy frigates operate the legacy GWS-26 Sea Wolf anti-air missiles so the ESSM's represent a significant upgrade in capabilities.

naval-technology.com

News, views

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Lockheed to support US Navy's MK41 vertical launching system

1

6 June 2014

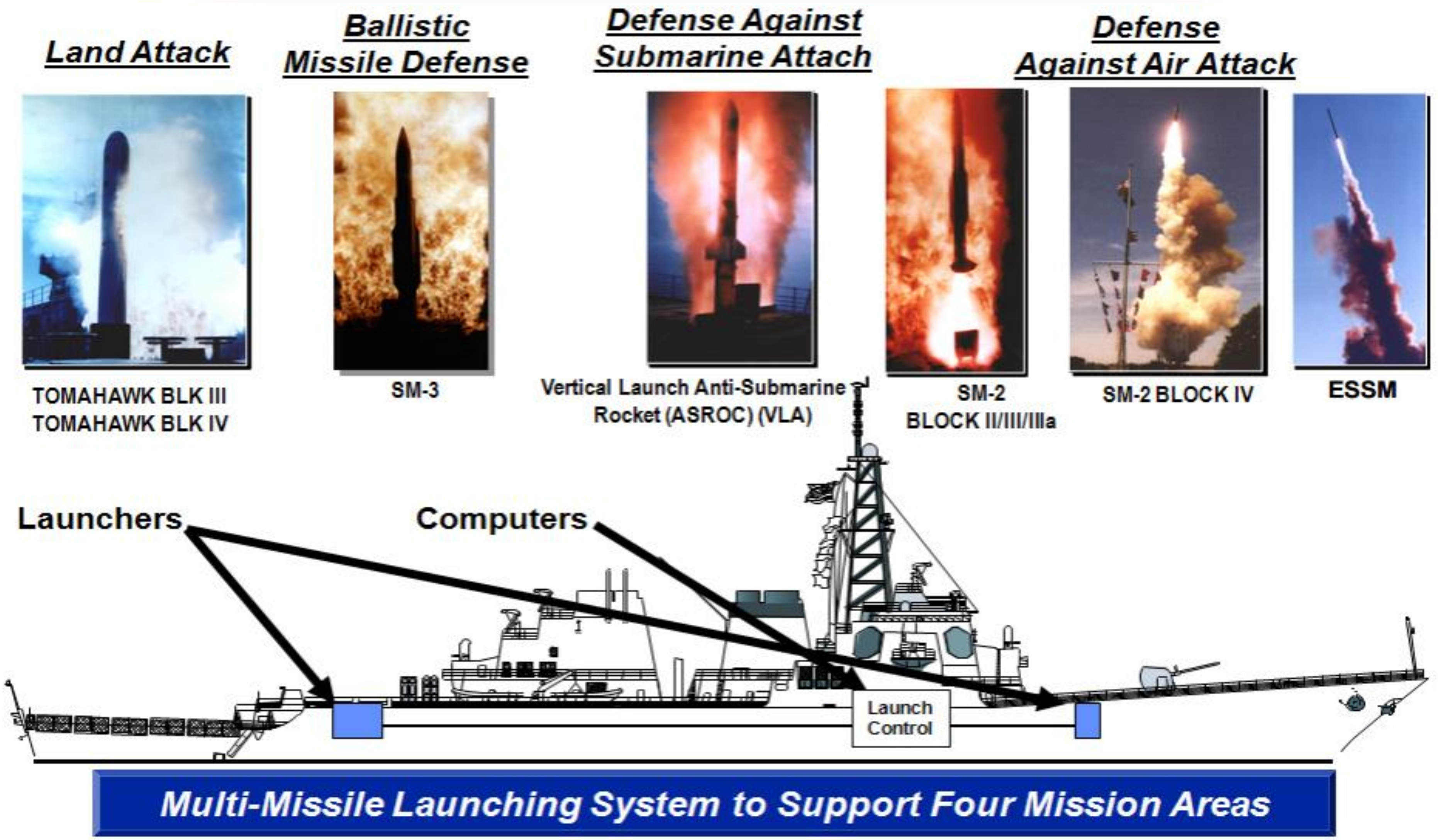
Lockheed Martin has been awarded a contract by the US Navy to provide engineering design services for its MK41 vertical launching system (VLS), which defends the naval fleet from numerous threats.

The $10m, cost-plus-fixed-fee contract also includes options, which, if exercised, will bring the overall value to $182m.

https://www.defenseindustrydaily.com/mk-41-naval-vertical-missile-launch-systems-delivered-supported-updated-02139/#TheHousing:VLSCells

http://www.naval-technology.com/news/newslockheed-to-support-us-navys-mk-41-vertical-launching-system-4287173

Vertical Launch Systems (VLS)



Vertical Launch Systems (VLS)

BAE Systems has received a $38.2 million contract modification from the U.S. Navy to provide additional missile canisters for the Mk 41 Vertical Launching System (VLS).

The company will supply more than 300 canisters of various configurations that will be used to store, transport, and launch different kinds of guided missiles from ships.

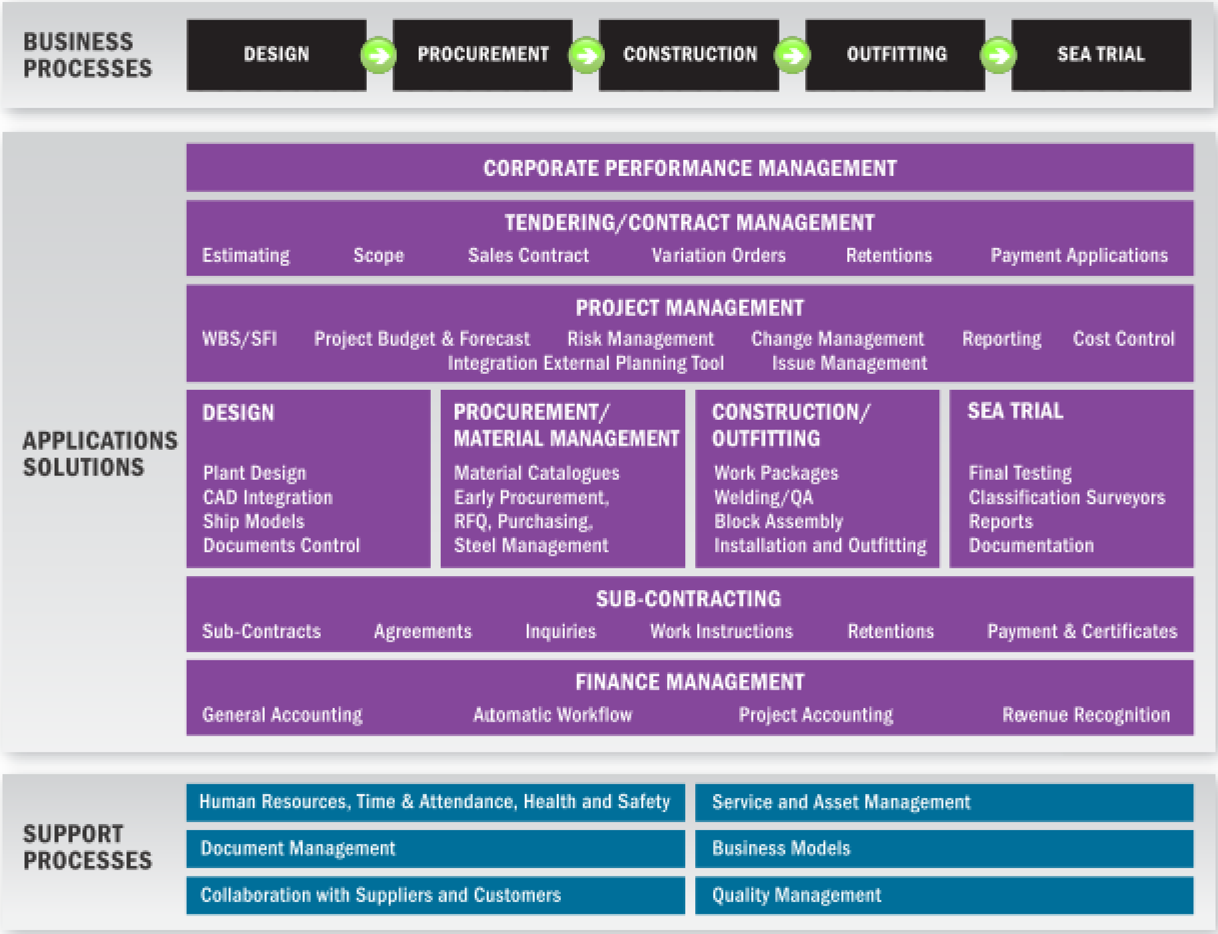
BAE Systems has been the Navy's exclusive designer and worldwide supplier of Mk 41 VLS canisters for more than 30 years. The company is also the Navy's Mk 41 VLS mechanical design agent, with more than 30 years of experience in the development, production, and support of the Mk 41 launching system.

forward Mk-41 VLS aboard USS Laboon (DDG 58)

http://www.seaforces.org/wpnsys/SURFACE/Mk-41-missile-launcher.htm

http://www.baesystems.com/en/article/bae-systems-lands--38-million-u-s--navy-contract-for-vertical-launching-system-canisters

Other Project Management Approaches in Shipbuilding



Scheduling Information from BIW Contactor According to GAO

Design Delays

Bath Iron Works planned to prepare production drawings using computer-aided design, but major problems arose. The computer equipment did not have adequate data storage capacity needed to design a complex warship. Design delays were also due to Navy changes in ship requirements, late government-furnished design data for the reduction gear, and difficulties with several developmental systems. As of November 1989, Bath Iron Works and Navy representatives believed that design problems had been resolved and production drawings were essentially complete. GAO believes that the installation and integration of the ship systems, which still has to be done, could surface additional design or performance problems.

Construction Problems

Design and other problems contributed to two revisions to the ship's scheduled delivery, totaling 17 months. The last revision to the delivery schedule was made in February 1988. The ship, originally scheduled to be completed in September 1989, is currently scheduled for delivery in February 1991. Bath Iron Works is accelerating construction to meet this date.

Bath Iron Works launched the lead ship in September 1989. According to Bath Iron Works representatives, the ship was more than 50 percent complete in October 1989. However, to complete the ship requires incorporating and integrating the AEGIS combat system and demonstrating that other systems, such as the collective protection system, work as designed.

In January 1989, the Navy modified the DDG-52 contract to provide for better helicopter support capabilities, which rescheduled the delivery date by 8 months. Also, the Navy has approved a proposal by Bath Iron Works to reschedule the DDG-53 construction schedule. The 7-month rescheduling will allow Bath Iron Works to more efficiently schedule its work on other ships it is building for the government. These ships will be delivered earlier than expected.

GAO

United States General Accounting Office
Report to the Secretary of Defense

January 1990

NAVY SHIPBUILDING

Cost and Schedule Problems on the DDG-51 AEGIS Destroyer Program

http://www.gao.gov/assets/150/148526.pdf

Electronic Warfare System & Project Investment

Lower Unit Cost Through Improved Manufacturing of SEWIP System

S2340 — Low-Cost Antenna Assembly for the Surface Electronic Warfare Improvement Program (SEWIP) Block 2 Electronic Warfare System

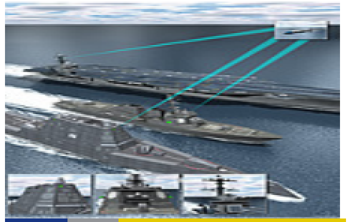
Objective

The intent of the Surface Electronic Warfare Improvement Program (SEWIP) Block 2 project was to upgrade the Navy's AN/SLQ-32 (V) electronic support measures system, which includes the system's receiver, antenna, and combat system interface. The Lockheed Martin (LM) team was selected by the Navy to provide the Integrated Common Electronics Warfare System (ICEWS) for SEWIP Block 2. This was a single enterprise solution designed to scale across all ship classes in the Navy's surface fleet. At-sea demonstrations of ICEWS in June 2009 were successful. The ICEWS maximized the reuse of SEWIP Block 1 elements and leveraged the LM Team's investment of $15M for a SEWIP Engineering Development Model (EDM) which was demonstrated at sea to achieve the lowest risk solution for Block 2. The ICEWS upgraded the receiver and antenna capabilities, as well as the combat system interface, of the legacy surface EW system. LM's scalable enterprise approach to ICEWS was based on the company's Rapid Commercial Off-The-Shelf (COTS) Insertion program, which has been used successfully on EW and sonar system upgrades on all classes of Navy submarines.

The objective of this project was to achieve a lower unit cost through improved manufacturing and ruggedization of the COTS SEWIP system elements, thus allowing the proposed elements to also meet the objectives of all SEWIP platforms including small ship Electronic Warfare (EW) systems, while improving producibility and lowering the unit cost for the standard SEWIP Block 2 System. This effort targeted the CVN 78 Class carrier program; however, classes such as DDG 51 and DDG 1000 would also benefit from implementation.

Payoff

The project addressed the desired cost targets and improved COTS hardware that did not meet system producibility. The project was developed to focus on the following: (1) improved manufacturability of the COTS Fiber Optic Transmitter, (2) improved manufacturability of the PDF Switch Matrix (RF Module), and (3) improved manufacturability of the RF Tuner. Implementation of the SEWIP ManTech developments has resulted in cost savings of $1M per ship hull.



PERIOD OF PERFORMANCE:
October 2010 to April 2012

PLATFORM:
CVN 78 Class / Carriers

AFFORDABILITY FOCUS AREA:
Electronic Processing and Fabrication

CENTER OF EXCELLENCE:
EMPF

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STAKEHOLDER:
PMS 378

TOTAL MANTECH INVESTMENT:
$2,516,000