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### **AEGIS Platforms: The Potential Impact of Open Architecture in Sustaining Engineering**

**26 October 2007**

**by**

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**Jennifer L. Ahart, ENS, USN,**

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# Abstract

This proof-of-concept case study analyzes the potential benefits of open architecture (OA) in the AEGIS software maintenance and upgrade process. In a multi-phased approach, the Knowledge value Added/Real-Options (KVA+RO) framework was applied to sustaining engineering on specific AEGIS software processes.

The KVA+RO framework provides decision-makers with a systematic approach for analyzing benefits and assessing risks of potential technological acquisitions. Results from our research indicate that implementing OA could result in substantial cost savings, optimal return on investment and increased benefits.



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Disclaimer: The views represented in this report are those of the author and do not reflect the official policy position of the Navy, the Department of Defense, or the Federal Government.



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# List of Abbreviations, Acronyms and Symbols

ACCESS/STARSY: AEGIS Software Database

AEGIS: Advanced Electronic Guided Interceptor System

CASREP: Casualty Report

CBM: Component Business Model

CDR: Critical Design Review

CPCR: Computer Program Change Request

CPDD: Computer Program Design Document

DoD: Department of Defense

ECP: Engineering Change Proposal

GIG: Global Information Grid

ICR: Interface Change Request

IWG: Integration Working Group

IWS: Integrated Warfare Systems

JCRB: Joint Change Review Board

KVA: Knowledge-value Added

KVA+RO: Knowledge-value Added and Real-options

MOE: Measure of Effectiveness

NMCI: Navy Marine Corps Intranet

NSWC: Naval Surface Warfare Center

OA: Open Architecture

OACE: Open Architecture Computing Environment

PAT: Preliminary Acceptance Test



PDR: Preliminary Design Review

PDS: Preliminary Design Specification

PEO IWS: Program Executive Office, Integrated Warfare Systems

RO: Real-options

ROI: Return on Investment

ROK: Return on Knowledge

SCCB: Software Configuration Change Board

SCP: Software Change Proposal

SDD: Software Design Document

SE: Sustaining Engineering

SHIPALT: Ship Alterations

SME: Subject-matter Experts

SOA: Service-oriented Architecture

SSDS: Ship Self-defense System

STR: Software Trouble Reports

TLT: Total Learning Time



The US Navy (Navy) must meet evolving national security requirements and build a fleet for the future in a time of shrinking budgets and aging platforms. Through open architecture (OA) principles and solutions, Naval systems could become more agile, modular, flexible and affordable. Naval Open Architecture, an enterprise-wide, multi-faceted business model and product-line strategy, is designed to exploit open system design principles and architectures.

This proof-of-concept case study quantifies the potential benefits of open architecture in the AEGIS software maintenance and upgrade process. In a multi-phased approach, the Knowledge-value Added/Real-options (KVA+RO) framework was applied to sustaining engineering in the AEGIS software maintenance and upgrade process. The KVA+RO framework provides decision-makers with a systematic approach for analyzing benefits and assessing risks of potential technological acquisitions.

This case study augments previous research by the Naval Postgraduate School (NPS) and analyzes the potential impact of OA from the warfighter perspective by extending that initial research into the development and acquisition processes of sustaining engineering (Uchytel, 2006). By extending our investigation into the acquirer and system-developer perspective, the researchers can provide a comprehensive view of the entire system development lifecycle.

In the first phase, KVA methodology was first applied under two scenarios: As-is and To-be. Results from our KVA analysis show that implementing OA could result in substantial cost savings, optimal return on investment and increased benefits. In particular:

- Costs for one ship decrease \$365,105; costs for all ships decrease by \$26,543,825 per year.



- Return on investment for one ship increases from 69% to 789%; ROI for all ships increases from 320% to 72,287%.
- Revenues (benefits) for one ship increase \$2,488,179 to \$3,837,931; revenues for all ships increase \$209,007,032 to \$322,386,181.

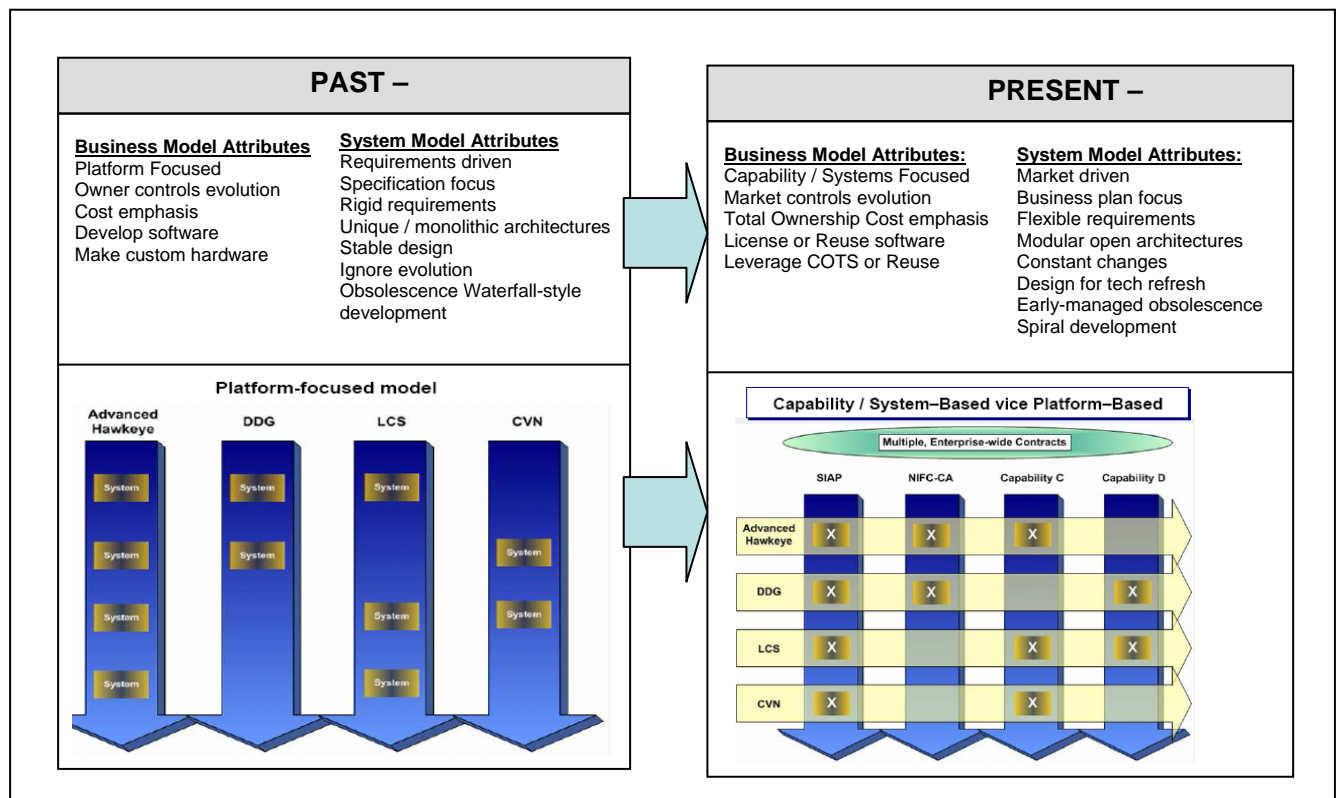
During Phase two, a real-options analysis was conducted on several strategic scenarios to assess risks associated with potential strategies for the AEGIS software maintenance and upgrade process. This paper presents the research in greater detail.



## 2.0 Naval Open Architecture

Naval Open Architecture (OA) is a multi-faceted business and technical strategy for acquiring and maintaining National Security Systems as interoperable systems that adopt and exploit open system design principles and architectures (Naval OA Strategy, 2007). It is a departure from the old acquisition model of purchasing stove-piped systems built for single uses, not designed to work in a networked environment.

**Figure 1. Past and Present Navy Enterprise Acquisition Models**  
(Shannon, 2007, May 9, p 15)



OA has led to creation of interoperable systems delivering improved capabilities in a shorter time frame. For instance, the Naval Air Systems Command Office, responsible for the E-2C Hawkeye command-and-control aircraft, faced both delays in enhancing capabilities for its mission computing system as well as



obsolescence by the time it was to be fielded. By adopting OA principles, new capabilities were integrated within 24 hours, and the acquisition cycle-time was reduced from seven years to two-and-a-half (Shannon, 2007, February). The submarine force sonar program increased performance seven-fold, cut real processing costs 60-fold and fielded four major improvements within five years (2007, February).

SOA is another solution the Navy enterprise is considering in building future systems beyond OA. A new shift is occurring in IT, enabled by several factors, including processing speed, storage, network technology and new business models. In the past, software was traditionally developed to support very specific requirements and was installed at very specific sites. Software has shifted to a service-oriented industry. This paradigm change will have a major impact on every organization.

Software is an increasingly important functionality in Naval combat systems. The size of the DDG 1000 combat system, for example, is expected to increase 35% to almost 1.8 MSLOC—larger than the AEGIS Baseline 7.1R (Horvitz E., Katz D.J., Rumpf, R.L, Shrobe, H., Smith, T.B, Webber, G.E, Williamson, W.E., Winston, P.H., Wolbarsht, James L., 2006)

### Figure 2. Size of Typical Naval Combat System

(Horvitz , Katz, Rumpf, Shrobe, Smith, Webber, Williamson, Winston, Wolbarsht, July 2006, p 29)

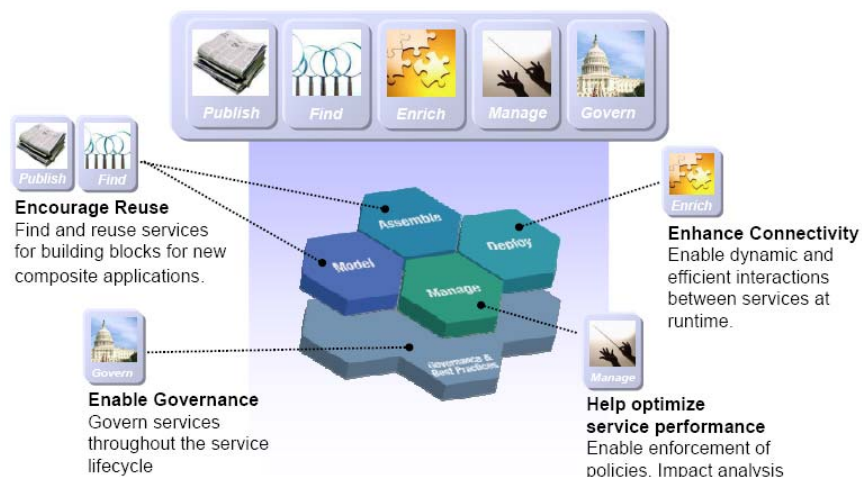




### 3.0 Service-oriented Architecture

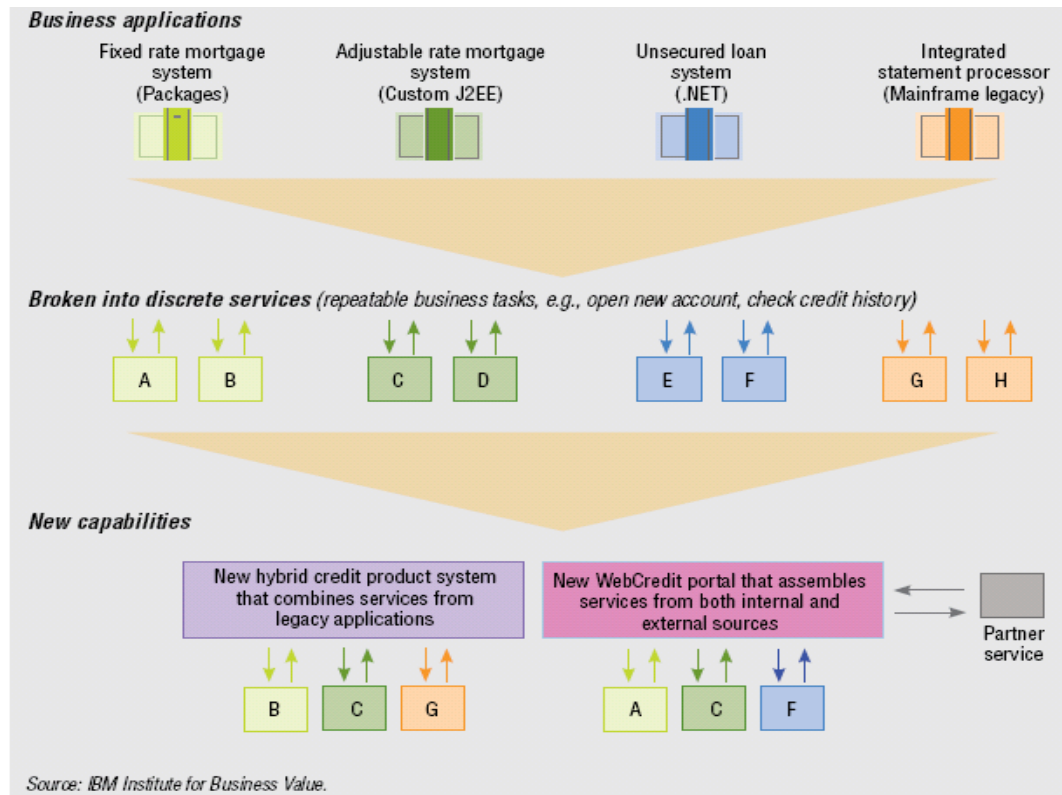
Service-oriented architecture is a business-driven approach providing increased flexibility, adaptability, agility, openness and cost-efficiency. It supports an information environment built upon loosely coupled, reusable, standards-based services. SOA promotes data interoperability rather than application interoperability, and with its use, capabilities can be reused—not recreated every time. According to Dr. Margaret Myers, Principal Director for the DoD Deputy Chief Information Officer, SOA ultimately provides the ability to discover, access and use data to the people that need it, when they need it.

**Figure 3. Service-oriented Software**  
(Shannon, 2007, May 9, p 10)



As seen in Figure 4, in SOA, business applications are broken down into separate functions (services) that can be used independently of applications and computing platforms. Organizations can integrate functions or create new capabilities as “building blocks” when individual functions within applications are available.

**Figure 4. SOA Illustration**  
(DiMare, Jay , 2006, p 4)



Research firm Gartner, Inc., believes SOA will be used in more than 50% of mission-critical operational applications and business processes designed in 2007 and in more than 80 percent by 2010 (cited in Govtech, 2007, April 26). In addition, Research 2.0 predicts that SOA will become status quo by 2015 (2007, May 31). Today, SOA is used by businesses around the world in virtually every industry, including:

- 10 of the world's largest auto manufacturers,
- 8 of the world's 10 largest banks,
- 9 of the world's 10 largest telecommunications companies,
- 8 of the world's 10 largest insurers, and
- half of the 30 largest electronic companies. (IBM, 2006, November)

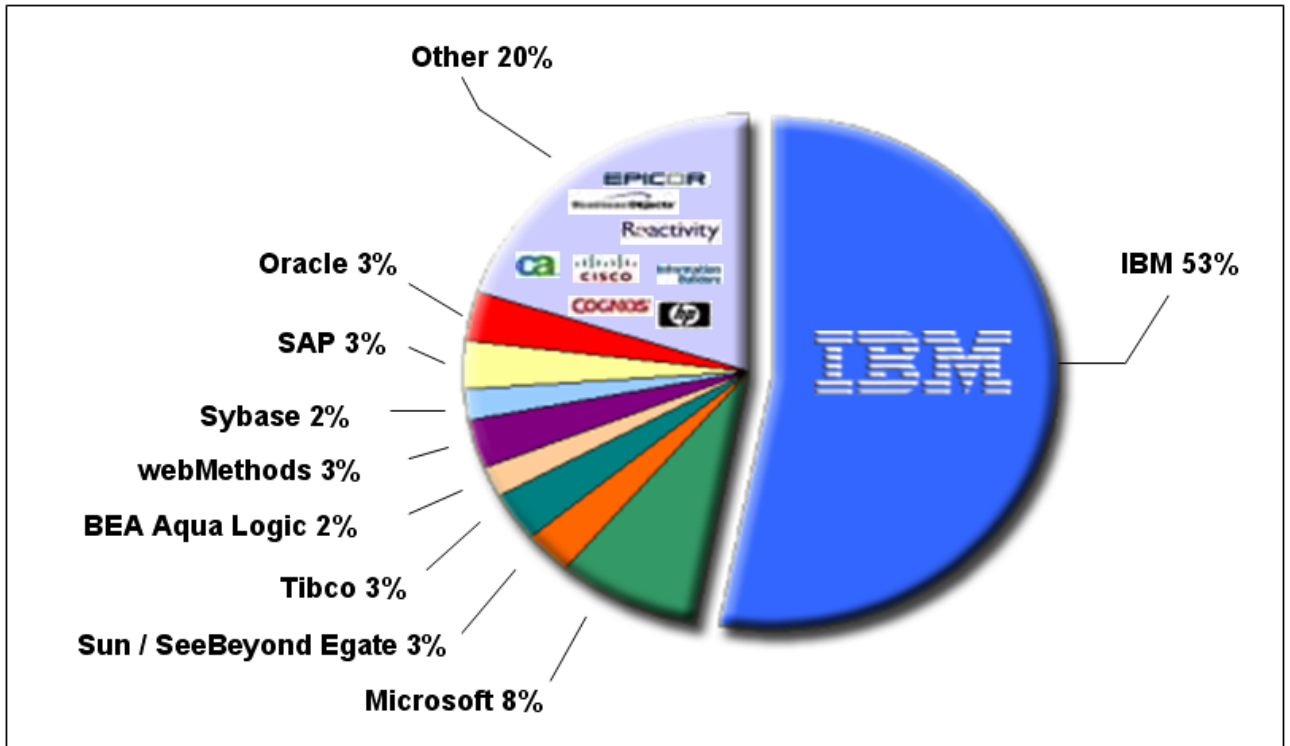


Companies are scrambling to gain traction in the rapidly expanding SOA space with industry analysts estimating that the SOA market could reach as much as \$160 billion. The SOA engine market is primed to grow from \$1.3 billion in 2006 to \$3.7 billion, according to WinterGreen Research (WinterGreen, 2007, May 16). A SOA engine is defined by WinterGreen as middleware providing a repository or process implementation for reusable code. Engines include application servers, repositories, ESB, XML compression, security capability, databases and mission-critical messaging.

IBM, Hewlett-Packard, Microsoft, Salesforce.com and Oracle all offer SOA-based offerings; IBM dominates the SOA infrastructure landscape with 53 percent of the market and implementations for 4,500 customers (Lawson, 2007, May 23). As seen in Figure 5, Microsoft is second with 8 percent; SUN, SAP and Oracle, webMethods and TIBCO all hold 3 percent of the market, while Sybase and BEA Systems each hold 2 percent (2007, May 23). IBM is the de facto industry-standard market leader given its depth of SOA offerings, client implementations, SOA-related patents and market share.



**Figure 5. Worldwide Services-oriented Architecture (SOA) Engine and Collaboration License, Services and Maintenance Market Shares, 2006**  
(Wintergreen, 2007, p 4)



Saugatuck Technology believes the industry will evolve in three waves and is in the middle of a 13-year adoption cycle. This projection is detailed in Table 1.

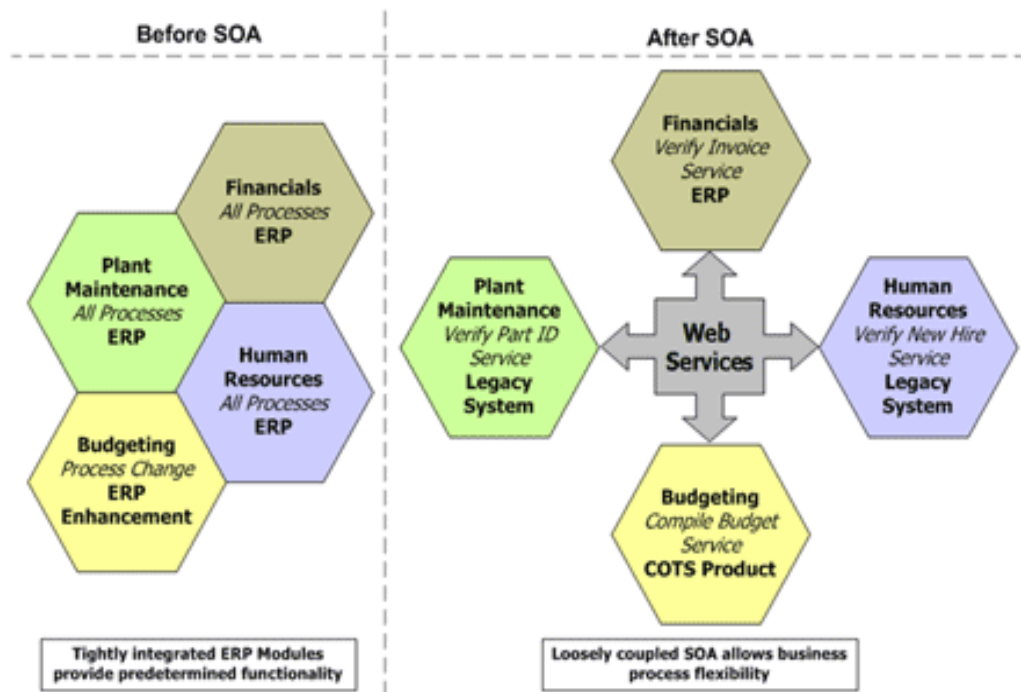
**Table 1. Three Waves of SOA**  
(Taft, 2007, May 28, p. 11)

<b>SOA Features</b>	<b>Wave I (1999-2005)</b>	<b>Wave II (1999-2005)</b>	<b>Wave III (1999-2005)</b>
<b>Deployment Focus</b>	Departmental initiatives; project-based	Cross-departmental; process-based	Enterprise wide; Program-based
<b>Vendor Value Proposition</b>	Integration via SOA and Web services	SOA enables business process flexibility	SOA as a foundational IT resource
<b>Representative Projects</b>	Portals; application and data integration	Sharing of services; cross-departmental process workflows	End-to-end business processes; composite applications

Although SOA is still in the early adopter stage, companies such as Wachovia, Cardinal Health and Royal Caribbean were among the companies discussing successful SOA implementations at a May 2007 IBM conference. At Cardinal Health, an \$81 billion global provider of health care products and services, SOA helped achieve a forty-fold boost in productivity. Processes that typically took the company 1,200 hours to perform required only 30 hours when using SOA technology (Taft, 2007, May 28, p. 11). For the most part, early adopters of SOA are service providers that have traditionally leveraged new technologies to differentiate themselves from the competition. Banks, insurers, engineers, telcos, and other businesses have automated and re-automated entire business process flows again and again (Research 2.0, 2007, May 31). Figure 6 illustrates how an IT architecture changes after adopting SOA.



**Figure 6. Before and After SOA**



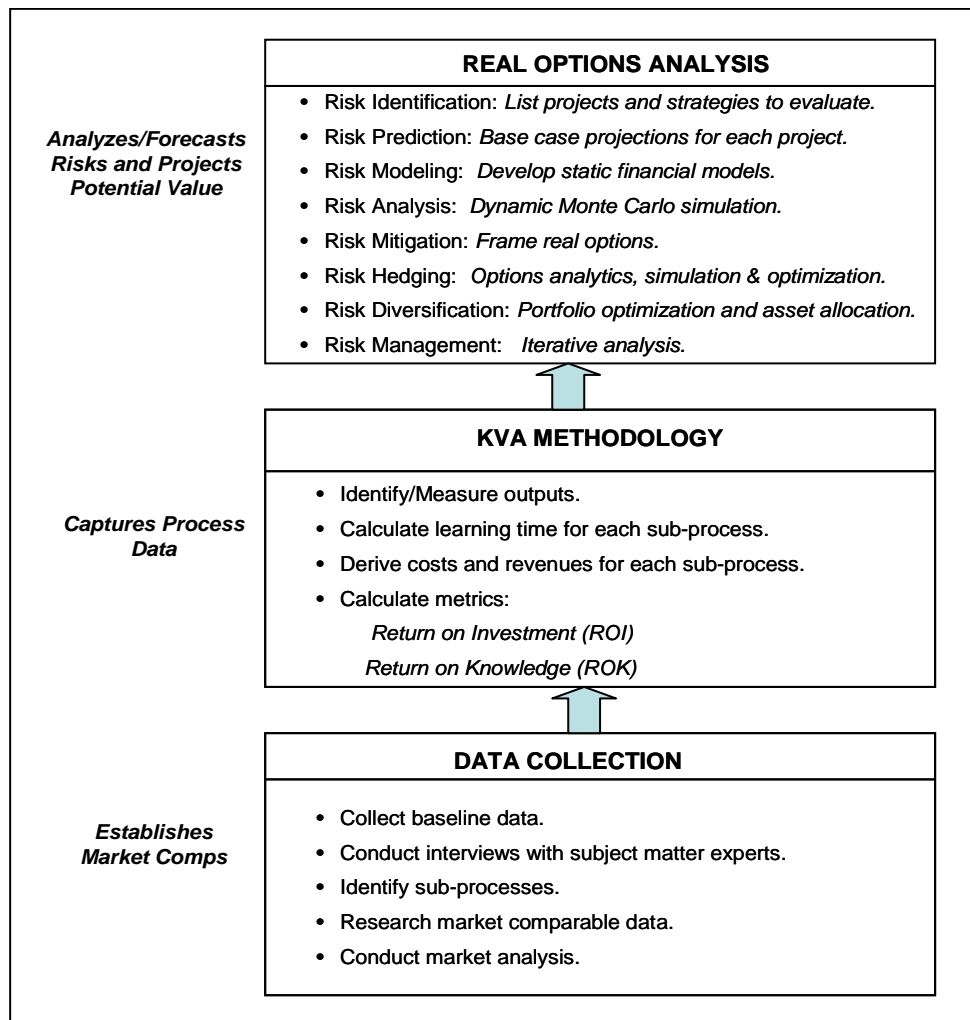
(Source: Enterprise Solutions Competency Center, U.S. Army PEO EIS & Software Engineering Center-Belvoir)

## 4.0 The KVA+RO Valuation Framework

KVA+RO is a comprehensive measurement process and an integrated tool set developed by NPS to measure and evaluate the total value of Naval acquisitions. It captures data across a spectrum of organizations to compare returns on investments, outputs, processes, capabilities, risks, strategic alternatives, costs, and value (i.e., comparable revenue). KVA+RO analytically quantifies uncertainty and risk elements inherent in predicting the future, includes ways to mitigate these risks through strategic options with analysis of alternatives, and analytically develops and allocates budgets to optimize project portfolios.



**Figure 7. KVA+RO Valuation Framework**



Large, complex organizations (ranging from publicly traded *Fortune* 500 firms to public-sector entities) can use the KVA+RO framework. Its focus on core processes, sub-processes, and outputs provides several advantages:

- Quantifies value of specific processes, functions, departments, divisions, or organizations in common units,
- Provides historical data on costs and revenues of specific processes and tasks of specific programs or organizations,
- Facilitates regulatory compliance in public-sector legislation—such as the *Clinger-Cohen Act of 1996* mandating portfolio management for all federal agencies,





- Highlights operational efficiencies/inefficiencies, and
- Leverages current and potential portfolio investments by estimating potential total value created.

By utilizing the KVA+RO framework, organizations can drill down to understand specific processes involved in the production of an output, the cost of each process and its contribution to the bottom line. Government entities can use the framework to enhance existing performance tools; on the corporate side, industry can employ the framework to value specific divisions or operating units to determine division profitability or shareholder value.

The KVA+RO framework has been used in a variety of NPS analyses, including:

1. *Shipyards Maintenance*

For one specific area of shipyard planning for maintenance alterations, the framework was projected to increase cost savings to exceed \$40 million per year and to drastically reduce manpower requirements using commercial-off-the-shelf, three-dimensional scanning/visualization technology and collaborative PLM technology. (Komoroski, C., Housel, T., Hom, S., & Mun, J., 2006, October)

2. *AEGIS and Ship Self-defense (SSDS) Platforms Track Management*

For certain elements of track management processes, upgrading existing IWS functionality were projected to have ROIs ranging from 212% to 404% for the AEGIS platform. For the SSDS platform, ROIs were also significant. (Uchytel, J., Housel, T., Hom, S., & Mun, J., Tarantino, E., 2006, October)

The KVA+RO framework is also being implemented in SPAWAR and in the Army Rapid Equipping Force project. It is being used in both projects to improve processes, reduce cycle-times and costs, and increase value. It both allows Navy

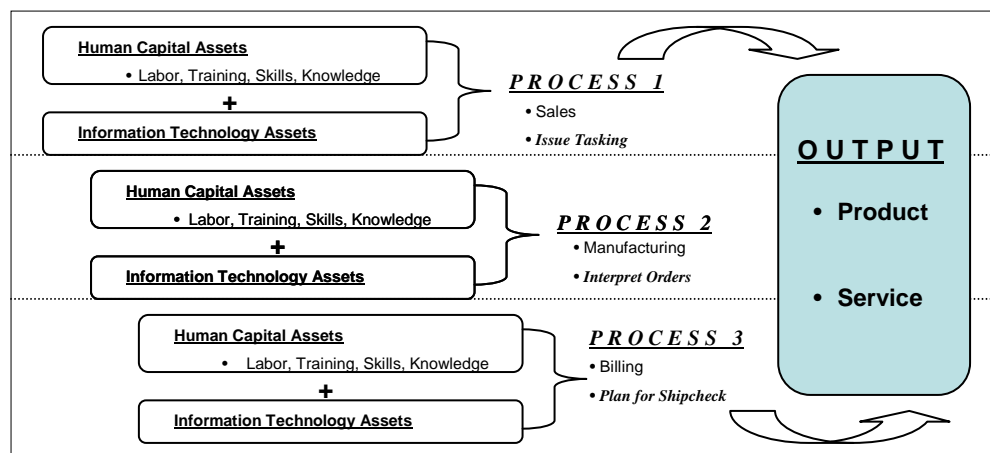


executives to acquire intelligence systems via a portfolio approach as well as distributies capabilities to Army troops in the field (i.e., Iraq and Afghanistan) very quickly through new rapid acquisition processes. Key framework components are discussed further below.

#### 4.1 KVA+RO Framework: Knowledge-value Added Methodology

KVA measures the value provided by human capital assets and IT assets by analyzing an organization, process or function at the process-level. It provides insights into each dollar of IT investment by monetizing the outputs of all assets—including intangible knowledge assets. By capturing the value of knowledge embedded in an organization's core processes, employees and IT, KVA identifies the actual cost and revenue of a product or service. Because KVA identifies every process required to produce an output and the historical costs of those processes, unit costs and unit prices of products and services are calculated. An output is defined as the end-result of an organization's operations; it can be a product or service, as shown in Figure 8.

**Figure 8 . Measuring Output**



For the past 15 years, KVA has been applied in over 100 organizations in the public and private sectors, ranging in size from under 20 employees to thousands. The methodology has been applied in 35 areas within the DoD, from flight simulation



applications to maintenance and modernization processes. As a performance tool, the methodology:

- Compares all processes in terms of relative productivity,
- Allocates revenues to common units of output,
- Measures value added by IT by the outputs it produces,
- Relates outputs to cost of producing those outputs in common units, and
- Provides common units of measure for organizational productivity.

By describing processes in common units, the methodology also permits market comparable data to be generated; this ability is particularly important for non-profits like the Navy. Using a Market Comparable approach, data from the commercial sector can be used to estimate price per common unit, allowing for revenue estimates of process outputs for non-profits. The Market Comparable approach also provides a common-units basis with which organization can define benefit streams, regardless of the process analyzed.

KVA differs from other nonprofit ROI models because it allows for revenue estimates, enabling the use of traditional accounting, financial performance and profitability measures at the sub-organizational level. Figure 9 shows differences between traditional accounting and process-based accounting methods.



**Figure 9 . Comparison of Traditional Accounting versus Process-based Costing**

Traditional Accounting		KVA Process Costing			
<i>Explains what was spent</i>	Compensation	\$5,000	Review Task	\$1,000	<i>Explains how it was spent</i>
	Benefits/OT	1,000	Determine Op	1,000	
	Supplies/Materials	2,000	Input Search Function	2,500	
	Rent/Leases	1,000	Search/Collection	1,000	
	Depreciation	1,500	Target Data Acq	1,000	
	Admin. And Other	900	Target Data Processing	2,000	
	<b>Total</b>	<b>\$11,400</b>	Format Report	600	
			Quality Control Report	700	
		Transmit Report	1,600		
		<b>Total</b>	<b>\$11,400</b>		

KVA also ranks processes by the degree to which they add value to the organization or its outputs. This assists decision-makers in identifying what processes really add value—those that will best accomplish a mission, deliver a service, or meet customer demand. Value is quantified in two key metrics: Return on Knowledge (ROK) and Return on Knowledge Investment (ROI). Calculations of these key metrics are shown in Table 2.

**Table 2. KVA Metrics**

Metric	Description	Type	Calculation
Return on Knowledge (ROK)	Basic productivity, cash-flow ratio	Sub-corporate, process level performance ratio	Outputs-benefits in common units/cost to produce the output
Return on Investment (ROI)	Same as ROI at the sub-corporate, process level	Traditional investment finance ratio	(Revenue-investment cost)/investment cost

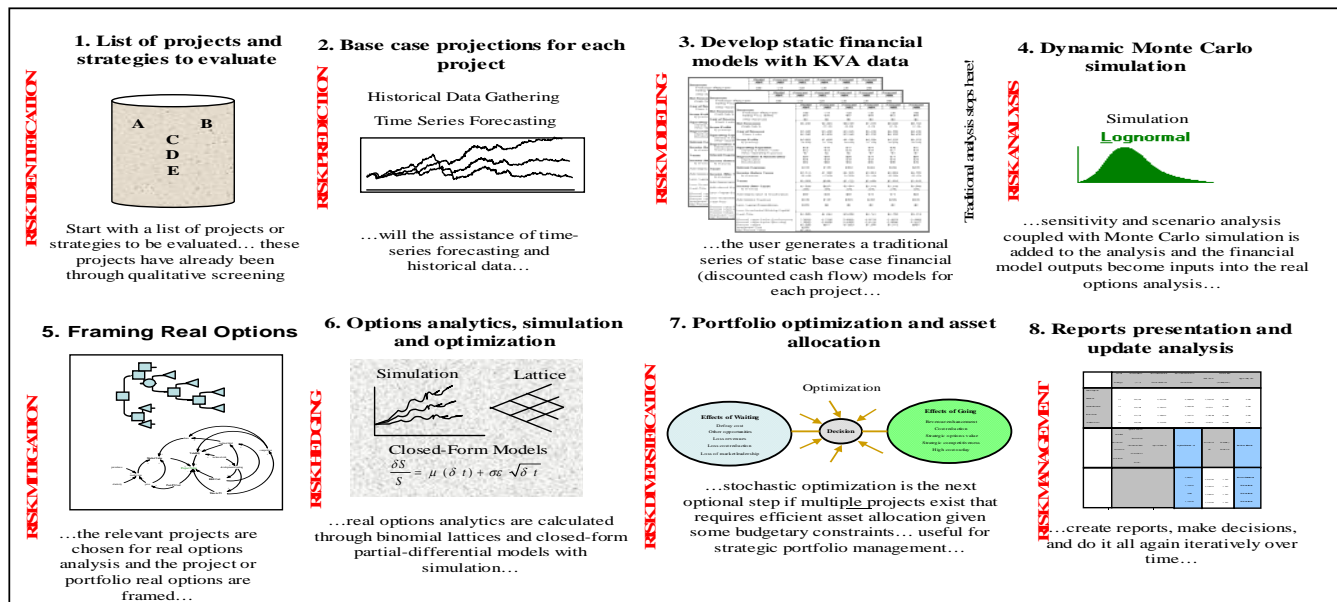
#### 4.2 KVA+RO Framework: Real-options Analysis

Potential strategic investments can then be evaluated with real-options analysis based on KVA data. The analysis applied is a robust and analytical process



incorporating risk identification (applying various sensitivity techniques), risk quantification (applying Monte Carlo simulation), risk valuation (applying real-options analysis), risk mitigation (utilizing real-options framing), and risk diversification (employing analytical portfolio optimization). Figure 10 reflects the complex calculations required for integrated risk analysis in the KVA+RO framework developed by Dr. Jonathan Mun.

**Figure 10. Integrated Risk Analysis Approach**



Real-options analysis incorporates strategic planning and analysis, risk assessment and management, and investment analysis. As a financial valuation tool, Real-options allows organizations to adapt decisions to respond to unexpected environmental or market developments. As a strategic management tool, real-options is a strategic investment valuation tool affording decision-makers the ability to leverage uncertainty and limit risk. Real-options can be used to:

- Identify different corporate investment decision pathways or projects that management can consider in highly uncertain business conditions,
- Value the feasibility and financial viability of each strategic decision pathway,

- Prioritize pathways or projects based on qualitative and quantitative metrics,
- Optimize strategic investment decisions by elevating different decision paths under certain conditions or determine how a different sequence of pathways can lead to the optimal strategy,
- Time effective execution of investments and find the optimal trigger values and cost or revenue drivers, and
- Manage existing or develop new options and strategic decision pathways for future opportunities. (Mun, 2005, p 3)



## 5.0 Case Study: Open Architecture and Sustaining Engineering on the AEGIS Platforms

In an audit conducted by a management consulting firm, sustaining engineering in the AEGIS system was identified as an area that could be reengineered to deliver high value. In a further analysis by NPS researchers, the AEGIS software maintenance and upgrade process was subsequently flagged as an area where OA would have a significant impact. This section provides the background information necessary for the proof-of-concept case study by introducing relevant concepts: distance support maintenance solutions, the component business model, sustaining engineering, and AEGIS software maintenance and upgrade processes.

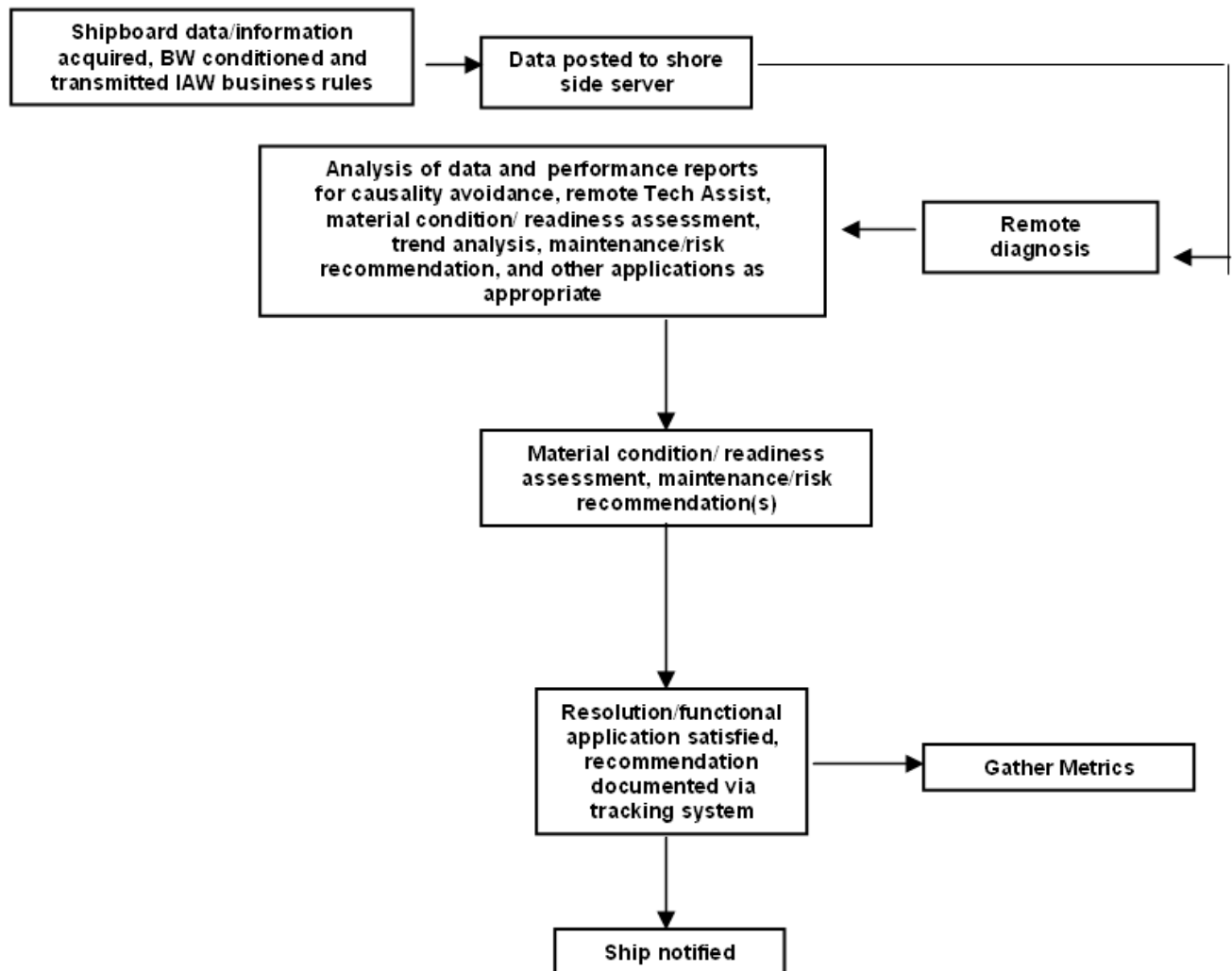
### 5.1 Distance Support Maintenance Solutions

According to the 2006 *Distance Support Policy* released by the Chief of Naval Operations, distance support is rapidly becoming “the Fleet’s principal web-based readiness enabler” (Chief of Naval Operations, 2006b, p 10). The current distance support system, at a minimum, “combines people, processes, and technology into a collaborative infrastructure without regard to geographic location” (2006b, p 20). It enables ships to be underway for several months and communicate with shore-based sites to fix software and hardware problems that occur onboard and, hopefully, resolve them without pulling into a foreign port or returning to the shipyards.

In the future, distance support will also include shore-based monitoring of systems, in much the same way that cars sold in 2006 and 2007 can communicate with central databases and give a report of their technical status. This form of distance support, called remote monitoring and notification, in a possible form of procedure for shipboard operations, is displayed in Figure 11 below.



**Figure 11. Remote Monitoring and Notification**



As seen in the figure above, shipboard information is constantly monitored in the “data/information acquired phase,” which then relays the information to the shore-side server for diagnostics and assessments of trends and material readiness. If there is a problem with the system’s maintenance, and risk recommendations are made, documented, and then analyzed in metrics, the ship is notified. If there is no detected issue, then the monitoring cycle will repeat and send a clean report to the ship.

When distance support is used correctly, it complements the tenets of OA quite effectively—if upgrades and the necessary changes can be made to an open





system. It allows for modularity and design reuse that can be distantly monitored and repaired rather than requiring a visit to port for the problem to be fixed. Additionally, as illustrated in the figure above, remote monitoring can provide automation in the process of upgrades and repairs; and automation, in most cases, leads to a decrease in the necessary number of employees.

## 5.2 Component Business Model

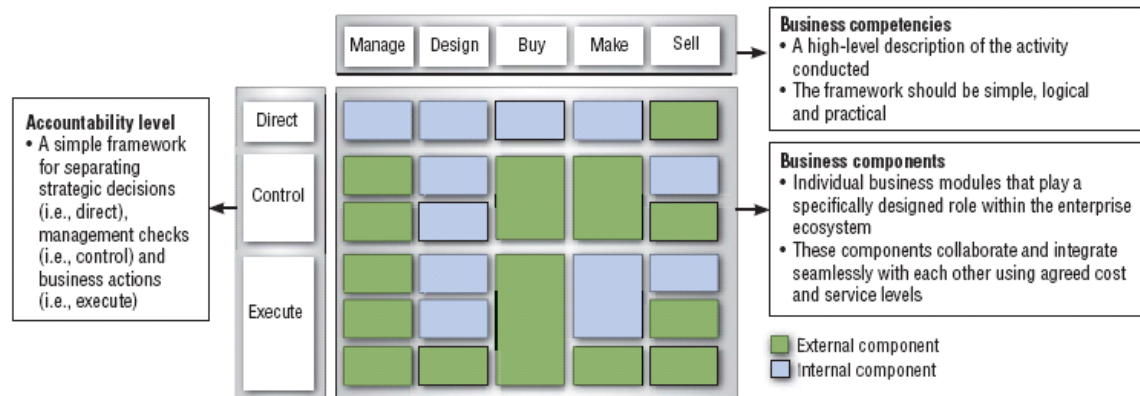
In an analysis conducted for Program Executive Office, Integrated Warfare Systems (PEO IWS), IBM used its CBM model to identify sustaining engineering as an area that could be significantly reengineered to deliver greater value. CBM, a tool developed by IBM, identifies opportunities across an enterprise for innovation and/or improvement” (Pavlick, 2005, p. 7). CBM breaks down the enterprise into business components consisting of resources, people, and technology that have the necessary information to deliver value from functional performance. Building component models (business maps) allow managers to frame decisions on a broader, organizational level and help identify areas offering the greatest opportunity for innovation/improvement. Each component encompasses five dimensions:

- A component’s business purpose is the logical reason for its existence within the organization, as defined by the value it provides to other components.
- Each component conducts a mutually exclusive set of activities to achieve its business purpose.
- Components require resources: the people, knowledge and assets that support their activities.
- Each component is managed as an independent entity, based on its own governance model.
- Each business component provides and receives business services, similar to a standalone business. (IBM, 2005)



CBM provides a framework for organizing components by competency and accountability level, as seen in Figure 12. The framework enables executives to envision how business activities might function.

**Figure 12. CBM Framework**  
(Pohle, G., Korsten, P., Ramamurthy, S., 2005, p 7.)



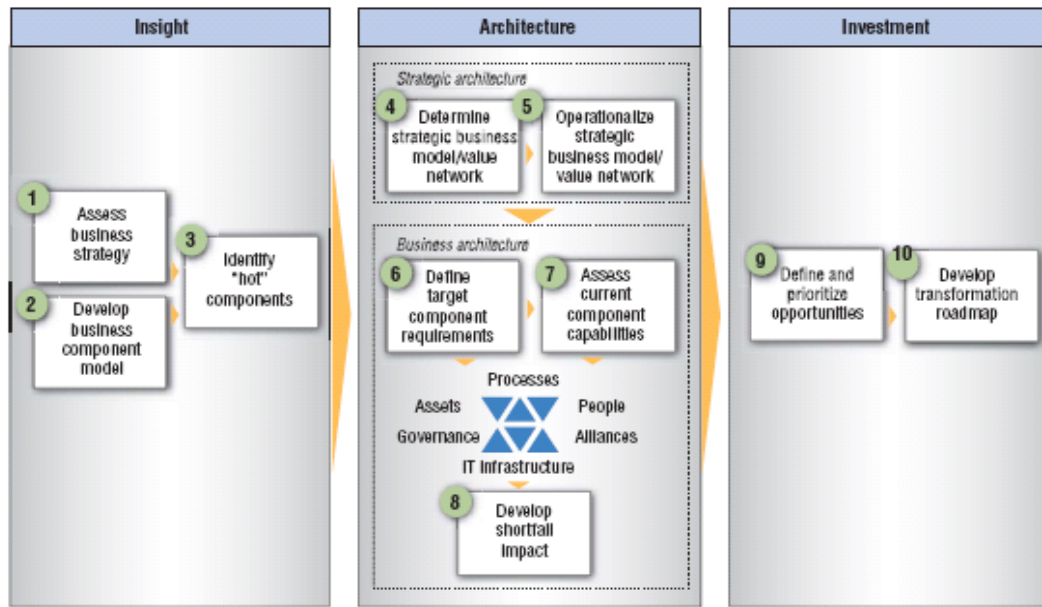
Source: IBM Business Consulting Services.

Key:

- Direct: Provides strategic direction and corporate policy to other components. Also facilitates collaboration with other components.
- Control: Serves as checks and balances between “direct” and “execute” levels. Monitors performance, manage exceptions and act as gatekeepers of assets and information.
- Execute: Provides business actions driving value creation in enterprise. Processes assets and information used by other components or end customer.

The component map provides a basis for developing strategic and operating insights for the business. By gauging the relative business value of different areas of the map, executives determine which components demand immediate attention. In addition, “hot” components are revealed representing the greatest economic value based on pre-defined attributes. There are three phases for the CBM framework, as shown in Figure 13.

**Figure 13. Phases of CBM Analysis**  
 ((Pohle, G., Korsten, P., Ramamurthy, S., 2005, p 10)



Source: IBM Business Consulting Services.

In the architecture phase, the goal is to identify gaps between the To-be vision of the componentized business and the As-is representation of how the organization presently organizes people, processes and technology.<sup>1</sup> The organization subsequently decides how to close the gaps in the last investment phase.

### 5.3 Sustaining Engineering

With the CBM tool, sustaining engineering in software maintenance and upgrade was flagged as an area for innovation and/or improvement. Figure 14 is the final component business map for the AEGIS weapons system; its “hot” components are represented by a star. IWS PEO selected three criteria to identify those “hot”

<sup>1</sup> To capture the full scope of the firm’s current capabilities and market positioning, this “as-is” representation must be firmly grounded in empirical data, such as organization charts, cost drivers, application portfolios, technology investments, key performance metrics and existing processes.


components: investment of total budget (green), number of efforts required for the task (yellow), and color of money (orange) (Shannon, 2006, p. 11).

SE has a medium percentage of the PEO IWS budget, a high number of efforts (greater than six), and two colors of money involved. The colors of money, or the money which is authorized/appropriated and used for specific acquisitions, are in the areas of Operation and Maintenance Navy (OMN) and Ship Building and Conversion Navy (SCN). The horizontal axis in Figure 14 represents a key competency, or one which requires similar skills and capabilities, while the vertical axis represents accountability levels. SE is the “System Sustainment and Disposal” competency, in which the “executing” branch, the branch that does the work, is accountable.

Additional secondary research revealed that as much as 80% of the total lifecycle costs of a system are incurred in the Operations and Support (O&S) phase of a system. Weapons system sustainment consumes about “80 percent of logistics resources, or approximately \$64B per year,” according to an article published in *Program Managers Magazine* (Kratz, Fowler, & Cothran, 2002, p. 2). Given that a large factor of the total lifecycle costs is in this O&S phase, it is as crucial that SE become much more efficient as the CBM report implied.



**Figure 14. AEGIS CBM Map**  
(Shannon, 2006, p. 14)

	System Acquisition Environment	Concept Development & Refinement	Technology Development	System Development & Demonstration	Production & Deployment	System Modernization	System Sustainment and Disposal	System Acquisition Support Services
Direct	Congressional Affairs	Warfighting Capability Concepts	Risk Strategy	Manufacturing Strategy	Production Strategy	Capability and Reliability Requirements	System Performance Strategy	Human Capital Planning
	OSD Affairs			Human Systems Integration Strategy		Modernization Policy		Training Strategy
	Acquisition Policy Development	Warfighting Data Strategy		Test & Evaluation Strategy		O&S Investment Planning	Facilities Planning	
	Warfighting Req. Planning			System Sustainment Strategy			O&S Investment Planning	IT Strategy
	Acquisition Investment Strategy	Technology Development Strategy		System Disposal Strategy		System Disposal Strategy		
	Trade & Export Control Strategy							
	Joint Integrated Architecture Strategy							
Control	Program Management & Monitoring M L SCN OWN	Acquisition Strategy	Acquisition Strategy	Acquisition Strategy	Acquisition Strategy	Technology Insertion Planning	System Performance Oversight	Legal
	External Collaboration and Partnership Management	Concept Development Planning & Oversight	Acquisition Planning L L OWN	Acquisition Planning L L OWN	Acquisition Planning L L OWN	Integrated Logistics Support Planning M M SCN OWN	Integrated Logistics Support Planning M M SCN OWN	Financial Management L L SCN
			Integrated Logistics Support Planning M M SCN OWN	Integrated Logistics Support Planning M M SCN OWN	Integrated Logistics Support Planning M M SCN OWN			Workforce Management
	Regulatory Compliance & Oversight	Modular Definition & Segregation	Technology Risk Assessment	Acquisition Performance Monitoring & Oversight	Manufacturing Oversight	Manufacturing Oversight	Enterprise Maintenance Planning	Contract Management
	Warfighting Technical Standards & Specifications			Developmental Test & Evaluation Oversight	Operational Test Planning & Oversight	Enterprise Modernization Planning	Obsolescence Mitigation Planning	Training Development
								Implementation Planning & Oversight M M SCN OWN
							Facilities H H SCN OWN ★	
Execute	Operational Integrated Architecture	Capability Requirements	Research & Technology Analysis	System Design & Integration H H ROTE SCN OWN ★	Low Rate Initial Production	Research and Development	Operator / Maintainer Training	Contract Preparation & Award
	Systems Integrated Architecture	Capability Assessment	Requirements Analysis	Developmental Test & Evaluation M M ROTE SCN	Operational Test & Evaluation M M ROTE SCN OWN	Configuration Management M M SCN OWN ★	Configuration Management M M SCN OWN ★	Financial Delivery
	Technical Integrated Architecture	Process Redesign	Modeling & Simulation L L OWN	Program Readiness Assessment M M SCN OWN	Live Fire Test & Evaluation M M SCN OWN	Ship/Airframe Modernization Planning L L OWN	Performance-Based Sustainment	Personnel Delivery
					Full Rate Production M M SCN OWN		Maintenance and repair planning	Training Delivery
							Sustaining Engineering M H SCN OWN ★	IT Delivery
							Organic Sustainment	Management
							System Disposal	



## 5.4 AEGIS Software Maintenance and Upgrade Processes

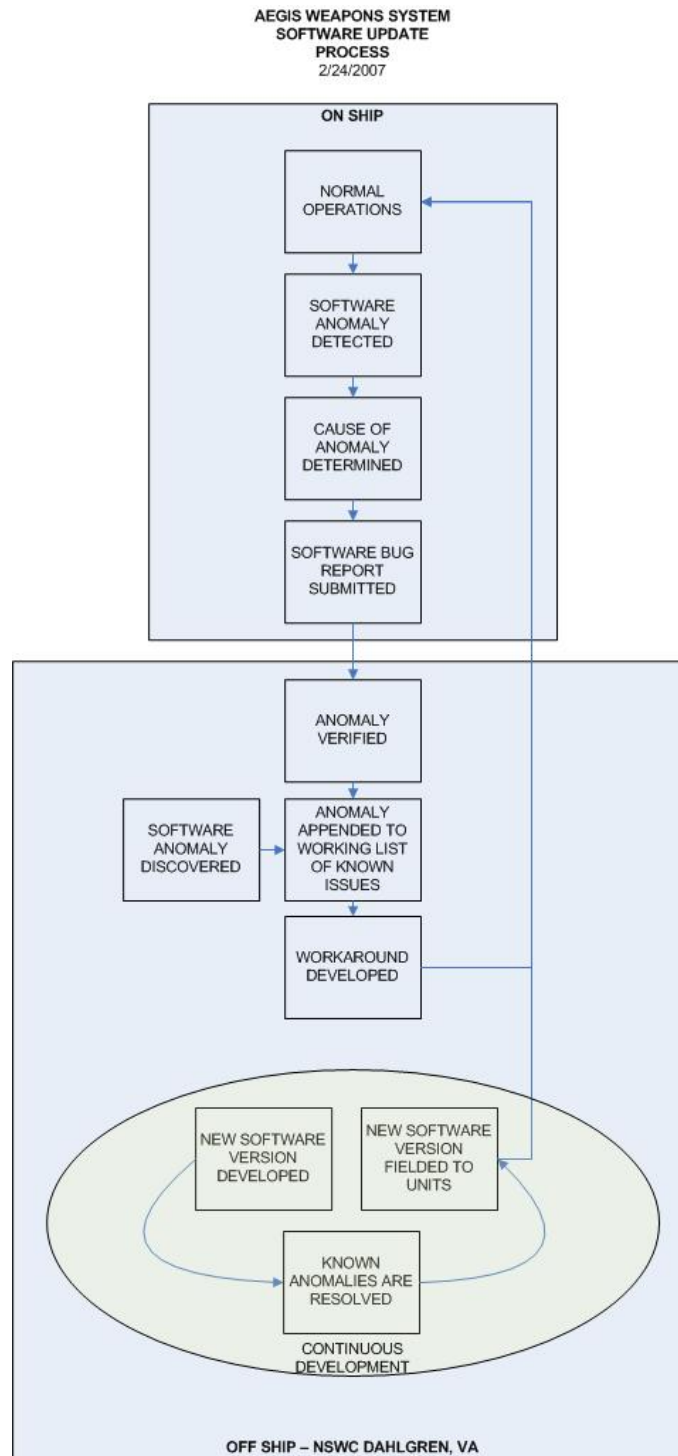
The AEGIS software maintenance and upgrade process is very complex. It involves a large number of processes in four main phases: requirements definition, design, test and implementation/installation. The entire AEGIS software upgrade lifecycle is intended to take 18 months, but typically takes closer to 24 months due to problems found during the testing phase or failure of certifications. This software maintenance and upgrade process involves many sub-processes in each one of its main processes. These sub-processes may or may not impact the rest of the processes in the software maintenance and upgrade process. The fact that some of these sub-processes may be able to function in a stand-alone capacity makes the analysis of the software maintenance and upgrade process very difficult.

The software maintenance and update process takes place in two primary areas: on-ship and off-ship. The on-ship portion takes place aboard AEGIS-equipped US Naval vessels and is conducted by Surface Warfare fleet personnel and various support personnel, including contractors. The on-ship portion is responsible for: identifying problems not found in the testing phase of the process, installation and on-ship testing of the fielded AEGIS software update. Two different departments detect AEGIS equipment and software failures and analyze their effects on mission capability.

Alternatively, the off-ship portion of the process takes place at the Naval Surface Warfare Center, Dahlgren, VA. This primarily deals with the requirements-definition phase, the design phase and the testing phase. Aggregated AEGIS software maintenance and update processes are shown in Figure 15.



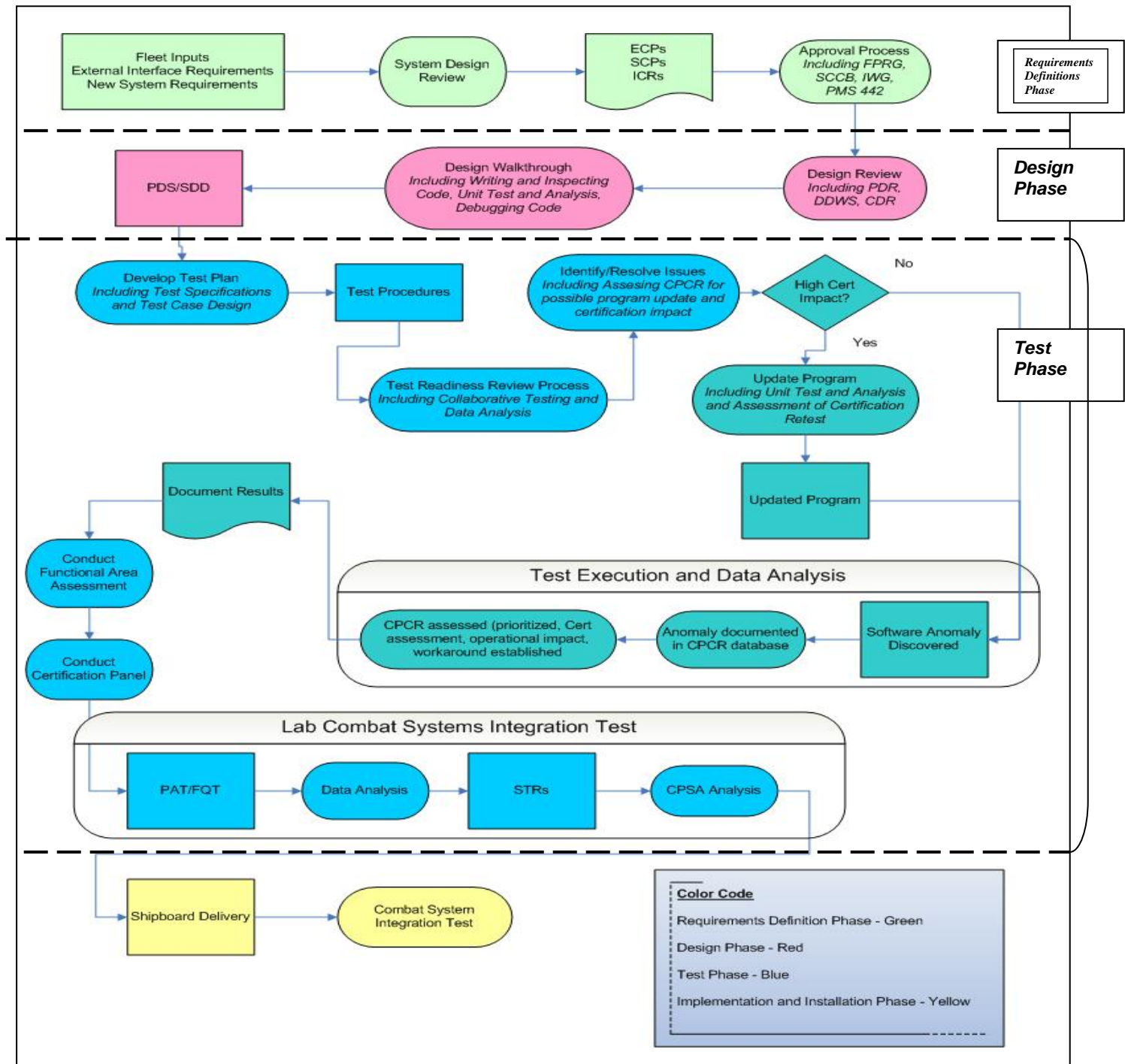
**Figure 15. AEGIS Software Maintenance and Update Process (Aggregate Level)**





A number of sub-processes are required in the off-ship software maintenance and update process, as seen in Figure 16.

**Figure 16. Off-ship Sub-processes**





## 6.0

## Case Study Results

The KVA+RO Framework was used to calculate the potential impact of OA on AEGIS software maintenance and upgrade processes. In a multi-phased approach, analysis was first conducted for one ship and then scaled up to include the entire AEGIS fleet of 84 ships. Data used in both analyses was derived from interviews with Subject-matter Experts (SME's), surveys and secondary research.<sup>2</sup>

KVA methodology was applied to on-ship and off-ship processes in these steps:

1. Identify core processes and sub-processes.
2. Establish common units and level of complexity to measure learning time.
3. Calculate learning time (i.e., knowledge surrogate) to execute each sub-process.
4. Designate sampling time period long enough to capture representative sample of the core processes' final product or services output.
5. Multiply learning time for each sub-process by number of times sub-process executes during sample period.
6. Calculate cost to execute knowledge (learning time and process instructions) to determine process costs.
7. Calculate ROK (ROK= Revenue/Cost) and ROI (ROI= Revenue-Cost/Cost).

Assumptions used in the case analysis included:

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<sup>2</sup> Collecting accurate data for KVA analysis was challenging given the complex software maintenance and upgrade processes, along with the large number of people involved. Only a few SMEs understand the full complexity of processes. In addition, outputs and learning time associated with each process and sub-process are not documented. This is coupled with the confusion that occurs between learning time and time spent in a Navy training course to learn the job. The Navy training courses are often of a uniform length of time, no matter the complexity of job, and subject-matter experts often confuse these training times with actual learning time. There is also a need to separate the time spent in a Navy training course or school learning the specific process and time spent learning other skills.



- Use of middleware was necessary until Category 4 OACE level could be reached.
- No process would become fully 100% automated.
- One employee would always be on-hand as a supervisor to even a mostly automated process.
- “Average Time to Complete” for the “New Software Version Fielded to Units” was estimated to be 15 minutes using the distance support concept.
- “Replacement Technology” would be used instead of “Additive Technology.”
- Development costs were not included because they are distributed throughout the lifecycle of system.

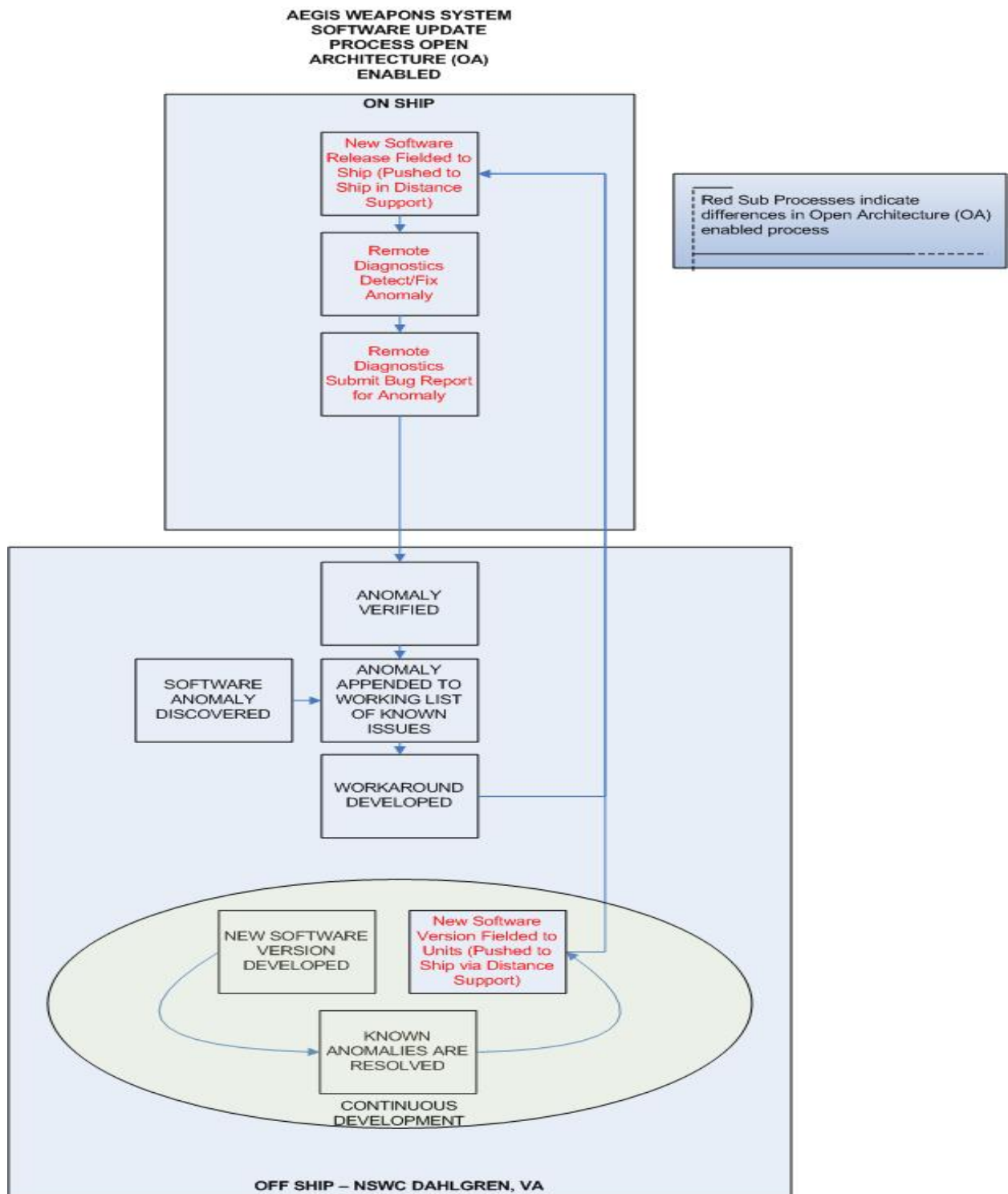
## 6.1 CASE STUDY RESULTS: KVA ANALYSIS

Results from the KVA analysis suggest that OA could have a significant impact on software maintenance and upgrade processes, as seen in Figure 17 below. Software updates are available via a push or pull method with OA. In the pull method, the user downloads and installs updates. Alternatively, in the push method, software is pushed to the network node remotely, thereby reducing onsite personnel while speeding up the upgrade process. Software updates are available through a secure link provided by Operational Readiness Test System Tech Assist Remote Support (ORTSTARS) in the latter scenario.

New software updates could be fielded to the ship through ORTSTARS in either method, resulting in reduced cycle-time fielding new software to its shipboard configuration. Remote diagnostics could also perform the functions involved in the “Combat System Integration Test,” further reducing cycle-time. Software fielding through distance support and the push/pull method would also reduce the number of personnel required to field the software to the unit—from three employees to one employee. The one process executor would still remain available to oversee the process and resolve any issues, via distance support, that the ship may encounter once the software has been fielded in its shipboard configuration.



**Figure 17. OA Enabled Software Update**



In particular, OA consolidates four sub-process (“**Software Anomaly Detected**,” “**Cause of Anomaly Determined**,” “**Software Bug Report Submitted**,” and “**New Software Version Fielded to Units**”) into two (“**Remote Diagnostics Detect/Fix Anomaly**” and “**Remote Diagnostics Submit Software Bug Report for Anomaly**”):

- *Remote Diagnostics Detect/Fix Anomaly.* Through ORTSTARS, a remote diagnostic identifies a software anomaly before an operator onboard identifies the anomaly. Circumstances surrounding the anomaly are recorded and compared to similar Computer Program Change Requests (CPCRs) managed in the ACCESS/STARSY database. If a PCR is found closely matching the anomaly detected, the remote diagnostics could then take appropriate actions already listed in the ACCESS/STARSY database to fix the anomaly.
- *Remote Diagnostics Submit Software Bug Report for Anomaly.* Through ORTSTARS, the software bug report could be submitted real-time through a secure link. With no human interpretation required, the software bug report would give a more accurate representation of circumstances surrounding the anomaly. Although the process still retains some human intervention as one process executor would still oversee the process, OA plus remote diagnostics could drastically reduce cycle-time by submitting the software bug report.

Based on KVA analysis, implementing OA could result in substantial cost savings, optimal ROI and increased benefits. As seen in Table 3, costs would decrease \$365,105 per ship. If OA was applied to all ships, costs would decrease by \$26,543,825 per year. ROI increases from 69% to 789% for one ship. And for all ships, ROI increases from 320% to 72,287%. Potential revenues (benefits) for one ship increases \$2,488,179 to \$3,837,931 and if OA is applied to all ships, revenues increase \$209,007,032 to \$322,386,181.



**Table 3. Costs for One Ship**

<b>Process/Revised Process</b>	<b>As-is</b>	<b>To-be</b>	<b>Potential Savings</b>
Software Anomaly Detected <i>New Release Fielded (Push to Ship via Distance Support)</i>	\$14,301	\$7,150	
Cause of Anomaly Determined <i>Remote Diagnostics Detect/Fix Anomaly</i>	\$251,597	\$50,319	
Software Bug Report Submitted <i>Remote Diagnostics Submit Software Bug Report for Anomaly</i>	\$1,430	\$1,430	
Anomaly Verified	\$17,021	\$17,021	
Anomaly Appended to Working List of Known Issues	\$1,307	\$1,307	
Workaround Developed	\$17,021	\$17,021	
New Software Version Developed	\$236,750	\$236,750	
Known Anomalies are Resolved	\$100,639	\$100,639	
New Software Version Fielded to Units	\$156,840	\$163	
<b>Totals</b>	<b>\$796,907</b>	<b>\$431,802</b>	<b>\$365,105</b>

**Table 4. Costs for All Ships**

<b>Process/Revised Process</b>	<b>As-is</b>	<b>To-be</b>	<b>Potential Savings</b>
Software Anomaly Detected <i>New Release Fielded (Push to Ship via Distance Support)</i>	\$14,301	\$7,150	
Cause of Anomaly Determined <i>Remote Diagnostics Detect/Fix Anomaly</i>	\$251,597	\$50,319	
Software Bug Report Submitted <i>Remote Diagnostics Submit Software Bug Report for Anomaly</i>	\$1,430	\$1,430	
Anomaly Verified	\$17,021	\$17,021	
Anomaly Appended to Working List of Known Issues	\$1,307	\$1,307	
Workaround Developed	\$17,021	\$17,021	
New Software Version Developed	\$236,750	\$236,750	
Known Anomalies are Resolved	\$100,639	\$100,639	
New Software Version Fielded to Units	26,349,120	\$13,723	
<b>Totals</b>	<b>\$26,989,187</b>	<b>\$445,362</b>	<b>\$26,543,825</b>



**Table 5. ROI (One Ship)**

Process/Revised Process	As-is	To-be
Software Anomaly Detected <i>New Release Fielded (Push to Ship via Distance Support)</i>	297%	3874%
Cause of Anomaly Determined <i>Remote Diagnostics Detect/Fix Anomaly</i>	236%	4605%
Software Bug Report Submitted <i>Remote Diagnostics Submit Software Bug Report for Anomaly</i>	2108%	39636%
Anomaly Verified	234%	234%
Anomaly Appended to Working List of Known Issues	1188%	1188%
Workaround Developed	78%	78%
New Software Version Developed	-36%	-36%
Known Anomalies are Resolved	-41%	-41%
New Software Version Fielded to Units	-36%	185408%
<b>Totals</b>	<b>69%</b>	<b>789%</b>

**Table 6. ROI (All Ships)**

Process/Revised Process	As-is	To-be
Software Anomaly Detected <i>New Release Fielded (Push to Ship via Distance Support)</i>	33278%	333681%
Cause of Anomaly Determined <i>Remote Diagnostics Detect/Fix Anomaly</i>	28133%	395159%
Software Bug Report Submitted <i>Remote Diagnostics Submit Software Bug Report for Anomaly</i>	185334%	3337713%
Anomaly Verified	27943%	27943%
Anomaly Appended to Working List of Known Issues	108113%	108113%
Workaround Developed	14856%	14856%
New Software Version Developed	5277%	5277%
Known Anomalies are Resolved	4841%	4841%
New Software Version Fielded to Units	-68%	185408%
<b>Totals</b>	<b>320%</b>	<b>72287%</b>



**Table 7. KVA Revenue Analysis for One Ship**

<b>Process/Revised Process</b>	<b>As-is</b>	<b>To-be</b>	<b>Difference (As-is, To-be)</b>
Software Anomaly Detected <i>New Release Fielded (Push to Ship via Distance Support)</i>	\$56,826	\$284,131	
Cause of Anomaly Determined <i>Remote Diagnostics Detect/Fix Anomaly</i>	\$845,629	\$2,367,761	
Software Bug Report Submitted <i>Remote Diagnostics Submit Software Bug Report for Anomaly</i>	\$31,570	\$568,262	
Anomaly Verified	\$56,826	\$56,826	
Anomaly Appended to Working List of Known Issues	\$16,837	\$16,837	
Workaround Developed	\$30,307	\$30,307	
New Software Version Developed	\$151,537	\$151,537	
Known Anomalies are Resolved	\$59,194	\$59,194	
New Software Version Fielded to Units	\$101,024	\$303,073	
<b>Totals</b>	<b>\$1,349,752</b>	<b>\$3,837,931</b>	<b>\$2,488,179</b>

**Table 8. KVA Revenue Analysis for All Ships**

<b>Process/Revised Process</b>	<b>As-is</b>	<b>To-be</b>	<b>Difference (As-is, To-be)</b>
Software Anomaly Detected <i>New Release Fielded (Push to Ship via Distance Support)</i>	\$4,773,407	\$23,867,035	
Cause of Anomaly Determined <i>Remote Diagnostics Detect/Fix Anomaly</i>	\$71,032,841	\$198,891,956	
Software Bug Report Submitted <i>Remote Diagnostics Submit Software Bug Report for Anomaly</i>	\$2,651,893	\$47,734,069	
Anomaly Verified	\$4,773,407	\$4,773,407	
Anomaly Appended to Working List of Known Issues	\$1,414,343	\$1,414,343	
Workaround Developed	\$2,545,817	\$2,545,817	
New Software Version Developed	\$12,729,085	\$12,729,085	
Known Anomalies are Resolved	\$4,972,299	\$4,972,299	
New Software Version Fielded to Units	\$8,486,057	\$25,458,170	
<b>Totals</b>	<b>\$113,379,149</b>	<b>\$322,386,181</b>	<b>\$209,007,032</b>





## 6.2 CASE STUDY RESULTS: Real-options Analysis

Three potential strategies were considered. In Strategy A, the As-Is alternative, there are really no strategic options available. It mandates keeping the system As-is and letting it retire over time. Therefore, the total strategic value is the net present value at \$196M. With Strategy B, the options are also limited; the option to wait and defer is not valued, and the total strategic value is also its net present value, valued at \$995M. Strategy C is an option to wait and defer with a proof-of-concept for the first year. After this initial test case, there is the potential for a follow-up option to expand into the next phase, generating a total net strategic value of \$1,236M. This significantly higher value comes in the form of being able to wait and defer a decision until risks and uncertainty become resolved over the passage of time, events, and actions, and in this case, the proof-of-concept results.

There is an option to abandon the methodology, should the results from the proof-of-concept prove to be under-performing expectations. If expectations are met, however, there is still the option to expand and execute the next To-be phase. Finally, in comparison, Strategy D, has a slightly lower uncertainty and volatility (the average volatility is slightly lower than in Strategy C), with a much higher total net revenue from all the phases. Its total strategic value is valued at \$1,482M, higher than that in Strategy C.

**Table 9. Real-Options Valuation Results: Strategies A-D**

	Strategy A	Strategy B	Strategy C	Strategy D
STRATEGIC OPTION	AS-IS (1)	TO-BE (W/out Changes in Fielding to Units)	TO-BE (1,3,4,5,6,7)	TO-BE (1,2,3,4,5,6,7)
Total Strategic Value	\$196M	\$995M	\$1.24B	1.48B
Volatility	10%	30%	60%	50%
Total Cost	\$208M	\$96M	\$30M	\$80M

**Key:**

1. As-is
2. Implement remote diagnostics/prognostics through ORTSTARS/Distance support, plus the ability of the crew to inject a trouble report through ORTSTARS/Distance support.
3. Number 2 plus providing software updates to the ship on media, then having the crew install with technician DS (remote) help. (Could also postulate a "sense and respond" sort of thing, in which





- a "local" tech is scheduled to the ship based on its availability and the update's arrival. Would count on local assets, not travel from Dahlgren...)
4. Number 3 plus notification of the ship that the update is available for download. Ship initiates download and installs with DS help.
  5. Number 4, except that the ship is notified that updates are available. The on-ship operators tell DS they're ready, and the remote tech takes control and installs the update.
  6. Number 4 except that the update is pushed to the ship, then cached until operators are ready to install. Ship installs with DS assistance if needed.
  7. Final state in which the update is pushed to the ship and installs during slack time, notifying the ship and allowing operators to say "not now."

## 7.0 Summary

This proof of concept case identifies the potential benefits of open architecture in the AEGIS software maintenance and upgrade process. Open architecture, built upon the tenets of open design principles and architectures, can assist the Navy in becoming a more agile, modular and cost-effective enterprise. As shown in this case analysis, implementing OA could result in substantial cost savings and optimal return on investment. In addition, the KVA+RO framework provides decision-makers with a systematic approach for structured analysis to evaluate those benefits and potential risks of differing strategies when implementing open architecture.



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## Appendix A. Distance Support Best Practice Example

### **Maintenance-free Operating Period (MFOP) and Acoustic Rapid Commercial Off-the-shelf (COTS) Insertion (ARCI)**

In 2005, Naval Sea Systems Command (NAVSEA) completed a pilot program to test the feasibility of a Maintenance-free Operating Period (MFOP) on the Acoustic Rapid COTS Insertion (ACRI) System. The ARCI system was designed to replace the AN/BSY-1 and the AN/BQQ-5 on the fleet's in-service submarines (688/688I/Trident/Seawolf) (Lockheed Martin, 2005). ARCI was a success in its own right, in that it effectively demonstrated the use of OA with COTS technology on a large scale in the fleet and allowed for technology insertion and refreshment (2005).

The ARCI MFOP program was conducted over a one-year time span, and it tested the use COTS technology and the COTS support provided to design ARCI in such a way to enable MFOP. Four platforms participated in the testing, and over the course of one year no maintenance was required in any of the four. One resulting benefit of this test, for the purposes of this research, was that the platforms implemented distance-support capabilities into the ARCI system before they conducted the test (NAVSEA Surface Warfare, 2005). Most particularly, the following results are applicable for the formulation of To-be models for AEGIS software maintenance and upgrade:

A database of maintenance related data was built into the ARCI system which provides the capability to perform statistical analysis of system performance and improve availability. An availability correlation function was developed to monitor system parameters and make recovery recommendations to system operators [...] An additional benefit of the MFOP Pilot Program was to develop and implement functionality in the ARCI system which further enables the system to be supported via Distance Support initiatives. (NAVSEA Surface Warfare, 2005)



Using the advances outlined above, the To-be models were formulated. The basis for those changes was grounded in research that has proven its MFOP reliability over the course of an entire year.





## Appendix B. Off-ship Sub-processes

<b><i>Inputs and Requirements</i></b>	Fleet inputs, external interface requirements and new system requirements gathered.
<b><i>System Design Review</i></b>	Technical review conducted to evaluate optimization, correlation, completeness, and risks associated with the allocated technical requirements.  Summary review of system engineering process producing allocated technical requirements of engineering planning for next phase also conducted (DoD, 1985).
<b><i>ECPs, SCPs, ICRs</i></b>	Required software changes are documented in Engineering Change Proposal (ECP), Software Change Proposal (SCP) and an Interface Change Request (ICR).
<b><i>Approval Process</i></b>	Change proposals and requests sent through an approval process in which the SCP awaits Software Configuration Change Board (SCCB) approval, and the ICR undergoes Integration Working Group (IWG) approval.  Aggregate approvals sent to NAVSEA program management for approval.
<b><i>Design Review</i></b>	First step in design phase of the AEGIS software maintenance and update process.  Process includes a preliminary design review (PDR) and a Critical Design Review (CDR).
<b><i>Design Walkthrough</i></b>	Process includes writing and inspecting code, unit test and analysis and code debugging.
<b><i>PDS/SDD</i></b>	Preliminary Design Specification (PDS) and Software Design Document (SDD) produced.
<b><i>Develop Test Plan</i></b>	First process in test phase of software maintenance and update process.  Test plan developed using test specifications and test-case design process.
<b><i>Test Procedures</i></b>	Test procedures, outputs of develop test plan process, later utilized in test execution and data-analysis process.
<b><i>Test Readiness Review Process</i></b>	Test plan and test procedures reviewed to ensure most effective test process.  Collaborative testing and data analysis included to achieve maximum efficiency.
<b><i>Identify/Resolve Issues</i></b>	Assessment of any CPCR's conducted for possible program update and also the certification impact of any CPCR's.
<b><i>Certification Impact Decided</i></b>	If any of the CPCR's are determined to have the potential for a high certification impact, then the program must be updated before it can be sent to the test execution and data analysis portion of the software maintenance and update process. If the CPCR's are not determined to have a high



	certification impact, the software, then, is sent directly to test execution and data analysis.
<b>Update Program (High Certification Impact)</b>	Software containing CPCR's determining to have a high certification impact must be updated. This includes another unit test and analysis and an assessment of the certification retest.
<b>Updated Program</b>	Software sent to test execution and data analysis after: program updated, unit test and analysis, and assessment of certification retest.
<b>Test Execution and Data Analysis</b>	<p>Software tested under lab conditions to detect potential problems prior to fully fielded software. Tests consists of three sub-processes:</p> <p>A. Software Anomaly Discovered</p> <p>A software anomaly is found under lab conditions.</p> <p>B. Anomaly Documented in CPCR Database</p> <p>A CPCR is generated for anomaly and then entered into ACCESS/STARS database.</p> <p>C. CPCR Assessed</p> <p>The CPCR is prioritized, and its certification impact is assessed. The CPCR's operational impact is also assessed, and, if possible, a workaround is established.</p>
<b>Document Results</b>	Test execution and data analysis results from software maintenance and update process documented.
<b>Conduct Functional Area Assessment</b>	Higher-level analysis to prepare software for certification panel review.
<b>Conduct Certification Panel</b>	A certification panel assesses the software's results from the test execution and data analysis process and certifies the software for fielding.
<b>PAT/FQT</b>	Preliminary Acceptance Test (PAT) and Functional Quality Testing (FQT) conducted on software.
<b>Data Analysis</b>	Data collected from PAT and FQT assessed and analyzed in preparation for the Lab Combat Systems Integration Test.
<b>Lab Combat System Integration Test</b>	Process includes any final testing that occurs in the lab environment, including any software trouble reports (STR) that are collected. CPSA Analysis and a CPSA report are gathered.
<b>Shipboard Delivery</b>	<p>New software is fielded to operational units and installed by teams of contractors and support personnel.</p> <p>Crew briefs and training conducted.</p>
<b>Shipboard Combat System Integration Test</b>	Software fully tested for shipboard configuration, functionality and interoperability with all combat systems already on the ship.



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