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Make or Buy: An Analysis of the Impacts of 3D Printing Operations, 3D Laser Scanning Technology, and Collaborative Product Lifecycle Management on Ship Maintenance and Modernization Cost Savings

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30 January 2016

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Abstract

The Naval Postgraduate School (NPS) conducted a trade-off analysis of in-sourcing versus outsourcing parts for ship maintenance and modernization with a focus on cost savings given the importance of strategic sourcing in cost-effective sustainment costs. The purpose of the study was to create the needed make/buy comparison for implementing 3DLST and 3DP for US Navy fleet maintenance and upgrading. In particular, cost estimates of in-sourcing and outsourcing were developed and the impact of in-sourcing on fleet readiness assessed. The results have several significant implications for fleet maintenance and modernization practice. The finding of significant potential savings with in-sourcing suggests that the three technologies have created a potential shift in the optimal acquisition modes for fleet parts. Based on the Rand model of in-sourcing and outsourcing acquisition, as the costs of producing few more different types of parts (e.g., simple vs complex and frequent vs. rare) drop with the new technologies, the Navy will be able to capture more benefits by in-sourcing more parts.

Keywords: Make-Buy, 3DPrinting, 3DLaser Scanning Technology, Fleet Maintenance, Real Options Analysis, ROI, Systems Dynamics

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***** This primer is written by Dr. Johnathan Mun, and is based on his two latest books, *Modeling Risk*, Second Edition (Wiley, 2010) and *Real Options Analysis,* Second Edition (Wiley, 2006).

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Executive Summary

Fleet maintenance and modernization are critical for the U.S. Navy to achieve expected service life of assets. With 288 ships in 12 ship-classes and numerous variations within those classes based at over 10 homeports, and the material condition of each ship so different, managing maintenance is extremely complicated and challenging. Service lives of ships range from 25 years for smaller, less-complex ships and up to 50 years for aircraft carriers. With lower spending on defense, the Navy must also continue to maintain weapons systems past their intended life while reconfiguring its depots to meet the maintenance needs of new systems designed for the evolution to the next generation of warfare.

Modernization often entails a ship being out of service for several years. Certain assets such as nuclear-powered submarines and aircraft carriers, for example, require lengthy and costly mid-life refueling overhaul, removing them from service. Guided-missile destroyers or cruisers getting a mid-life modernization overhaul are also unavailable for deployment for extended periods. For Aegis cruisers and destroyers to be installed with “Advanced Capability Build 12,” the process requires gutting the ship.

Traditional ship maintenance and modernization tools and methods employ extensive acquisition processes, reverse engineering, and manufacturing of replacement parts when performed by outside contractors. In-sourcing these operations using 3 Dimensional Printing (3DP), 3 Dimensional Laser Scanning Technology (3DLST), and Collaborative Product Lifecycle Management (CPLM) can reduce fleet maintenance costs. Whether to outsource or in-source parts manufacturing using these technologies requires estimates of potential savings using different make/buy strategies. A comparison of in-sourcing and outsourcing 3DLST and 3DP for fleet maintenance and upgrading is needed to capture all the available cost and performance benefits of these technologies in either condition.

The Naval Postgraduate School (NPS) conducted a trade-off analysis of in-sourcing versus outsourcing parts for ship maintenance and modernization with a focus on cost savings given the importance of strategic sourcing in cost-effective sustainment costs. The purpose of the study was to create the needed make/buy comparison for implementing 3DLST and 3DP for US Navy fleet maintenance and upgrading. In particular, cost estimates of in-sourcing and outsourcing were developed and the impact of in-sourcing on fleet readiness assessed.

The project addressed several important issues:

1. What are the relative costs of in-sourcing 3DLST and 3DP fleet maintenance and modernization compared to outsourcing those same operations with contractors using these two technologies?
2. What are the impacts of in-sourcing 3DLST and 3DP on fleet maintenance and modernization compared to outsourcing those operations with contractors using the two technologies?
3. How does in-sourcing versus outsourcing, using 3DP and 3DLS, affect cost and fleet readiness?

Primary and secondary data was collected on current operations and costs. Primary research data was collected on US Navy 3DP operations at the Naval Surface Warfare Center, Port Hueneme Division. Secondary research was collected from publicly available sources. Based on this research, cost models were developed to estimate start-up costs, potential operations costs and cost savings, and estimates of cycle time reductions in fleet maintenance and modernization possible under five make/buy strategies. The models were then used to simulate different levels of outsourcing to estimate the initial costs, potential cost savings, and cycle time reductions in fleet maintenance and upgrading possible under five scenarios shown in Table ES1.

Table ES1. Five Make/Buy Scenarios

STRATEGY	SUMMARY	RISK LEVEL	ISSUES
Strategy A: BASE CASE	Keep purchasing majority of inventory.	High	• Opportunity losses are occurring due to missed financial savings and control over the process in the long run.
Strategy B: OUTSOURCE	Outsource all manufacturing to outside contractors.	High	• Leads to dependency on organizations outside of Navy control. • Navy could implement Open Architecture principle that provides interchangeability of critical parts on a ship without any loss of functionality to reduce risk of dependency on few vendors. That gives the Navy the flexibility to choose vendors based on objective parameters (price, frequency, availability). • Exit strategy not expensive. Navy can easily go to other options without any substantial costs.
Strategy C: INSOURCE	Manufacture everything "in-house" immediately.	High	• ROI high; costs and risks very high if it does not work out. • Savings may be captured by using 3DLST, 3DP, and CPLM for fleet maintenance and modernization. • Exit strategy costly to abandon due to high investment costs.
Strategy D: SEQUENTIAL COMPOUND	Phased implementation.	Moderate	• ***PHASE I. 25% PLM: Implement PLM.*** Strategic business approach applying a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise. • ***PHASE II. 50%: 3D Laser Scanning Technology***. Small-scale investment over time with the ability to exit and walk away should the technology not work out as expected. Phasing investments over time hedges any downside risks and reduces any risks of large lump-sum investments. • ***PHASE III. 75%: Additive Manufacturing***. 3D CAD models, Conversion to Stereo-lithography STL, Revision of STL Models, AM Machine Setup and implementation. 3D Technology could be still applied in other operations of the Navy. • ***PHASE IV. 100%: Final Phase.*** Implement the PLM, 3DLST technology for all required inventory parts. Now too costly to abandon.

The following are the key findings from the project:

- ***3DP technology is evolving rapidly***. The U.S. military is already implementing the technology in the field. In July 2012, the Army deployed its first mobile 3D printing laboratory in Afghanistan inside a shipping container carried by helicopter.
- ***The U.S. Navy has supported research into 3D printing for more than 20 years.*** There are approximately 70 additive manufacturing projects underway at dozens of different locations, and the Navy is developing an overall vision and strategy.

- ***3DP has resulted in 43% cycle time reduction and 48% cost reduction for some aerospace firms***. The use of 3D laser scanning technology is increasingly being used in a growing number of industries, and early results have shown significant cost savings, optimized maintenance schedules, increased quality, improved safety, and reduced re-work.

- ***In-sourcing continues to be a heavily debated issue despite successes where the government has saved money.*** The Industrial Supply Center (FISC) Puget Sound saved the Navy $2.7 million over five years. The Federal Aviation Association (FAA) Tech Center in-sourcing initiative saves between $52 and $203 million in data system costs over the life of the project. The Army claims in-sourcing resulted in savings of 16–30% and that in-sourcing was largely responsible for reducing the Army's contract services obligations from $51 billion in 2008 to $36 billion in 2010.

- ***Savings increase with the volume of parts manufactured by the Navy (more in-sourcing).*** Savings at the depot studied by having the Navy instead of industry produce all parts are estimated to be $12,673,000 ($28,152k–$15,479k) per year at the depot investigated. Assuming 10 depots that apply this strategy implies savings that exceed $120 million annually. Estimated annual savings are shown in Table ES2.

Table ES2. Estimated Annual Savings of Five Make/Buy Strategies

Savings at the depot studied by having the Navy instead of industry produce all parts (in $1000): $ 12,674

Estimated Annual Benefits of Five Make/Buy Strategies

% Made by Navy	High Complexity 25%		Medium Comp. 50%		Low Complexity 25%		Parts Produced		
	Industry	Navy	Industry	Navy	Industry	Navy	Industry	Navy	Total
0%	40,500		40,500		6,750		87,750		87,750
25%		40,500	40,500		6,750		47,250	40,500	87,750
50%		40,500	20,250	20,250	6,750		27,000	60,750	87,750
75%		40,500		40,500	6,750		6,750	81,000	87,750
100%		40,500		40,500		6,750		87,750	87,750

- ***Of the four make/buy strategies evaluated, the phased implementation approach (Strategy D) has the highest strategic value.*** This strategy involves implementing new technologies in phases, thus giving management the ability to exit at any stage of the project, while minimizing the risk of losses. Table ES3 shows the differing make/buy strategies.

Table ES3. Four Make/Buy Strategic Alternatives

Strategy Path	Decision	Strategic Value ($M)	Notes
Strategy A	25% Navy As-Is	62,300	AS-IS 25%
Strategy B	Buy 100%	59,597	Buy 100%
Strategy C	Make 100%	72,271	Make 100%
Strategy D	Phased	74,149	Stepwise

Phases	Cost ($M)	Timing
Phase 1 Cost	3,319	2 Years
Phase 2 Cost	3,319	4 Years
Phase 3 Cost	5,522	6 Years
Phase 4 Cost	3,319	8 Years
Total Costs	15,479	

This report presents the research in detail. In the Introduction section, differing types of maintenance work are discussed, maintenance budgets at the DOD and the Navy are highlighted, and the Navy Depot Maintenance Strategic Plan (2014–2019) is introduced. The Problem Description section discusses cost issues and describes them in further detail. The Background section provides background information on the decades-long, in-sourcing debate within the federal government, issues, legal challenges and advantages/disadvantages. In the Additive Manufacturing, Collaborative Product Lifecycle Management and 3 Dimensional Laser Scanning Technologies section, an introduction to 3 DP, 3DLST and CPLM is provided. This section begins with a discussion of the hype surrounding 3DLST, the potential and the cost and efficiency savings achieved in government and business. In the Research Approaches and Methods section, estimates of cost savings derived by three technologies (3DLST, 3DP, and CPLM) on fleet maintenance costs are provided. In the following section, a model was developed using the Knowledge Value Added framework to develop baseline data and applied to those three technologies. In the Real Options section, real options analysis was conducted on four implementation scenarios. Real options techniques allow a way of approaching problems by estimating return on investment (ROI) and the risk-value of various strategic real options. This technique was then used to both provide preliminary analyses and to build a strategy that reduces the risks of financial losses. In the final section, project conclusions and recommendations are presented.

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Introduction

Ship maintenance and modernization—repairs and improvements to the existing fleet—are central to U.S. Naval operations. The current cost-constrained environment within the federal government and the U.S. Department of Defense (DOD), as well as evolving threats, require Naval leadership to maintain and modernize the fleet to retain technological superiority while simultaneously balancing budget cost constraints and extensive operational commitments. Downsizing forces potentially threatens fleet readiness. At the same time, Navy leadership must navigate a complex technology acquisition process. The Navy spends billions annually on ship maintenance programs. Maintenance programs play a critical role in meeting Navy objectives.

New technologies can facilitate meeting fleet readiness requirements within cost constraints, but only if those technologies are adopted and applied effectively and efficiently. One of the most important issues in addressing these challenges concerns what work to in-source within Navy organizations and what work to outsource, that is, the "make versus buy" decision. As will be described, both in-sourcing (make) and outsourcing (buy) have been promoted as cost-savings tools. Currently, the impact of new technology adoption on the make/buy decision is unclear.

DOD maintenance accounted for 12% of the total DOD resource allocation of $652.3 billion—about $79.5 billion in FY2012. As seen in Figure 1, this $79.5 billion effort required approximately 645,000 military and civilian maintainers and thousands of commercial firms—all devoted to the maintenance of roughly 14,800 aircraft; 896 strategic missiles; 386,600 ground combat and tactical vehicles; 256 ships; and myriad other DOD weapon systems to maintain strategic materiel readiness. ((OASD[L&MR], 2013, p.i)

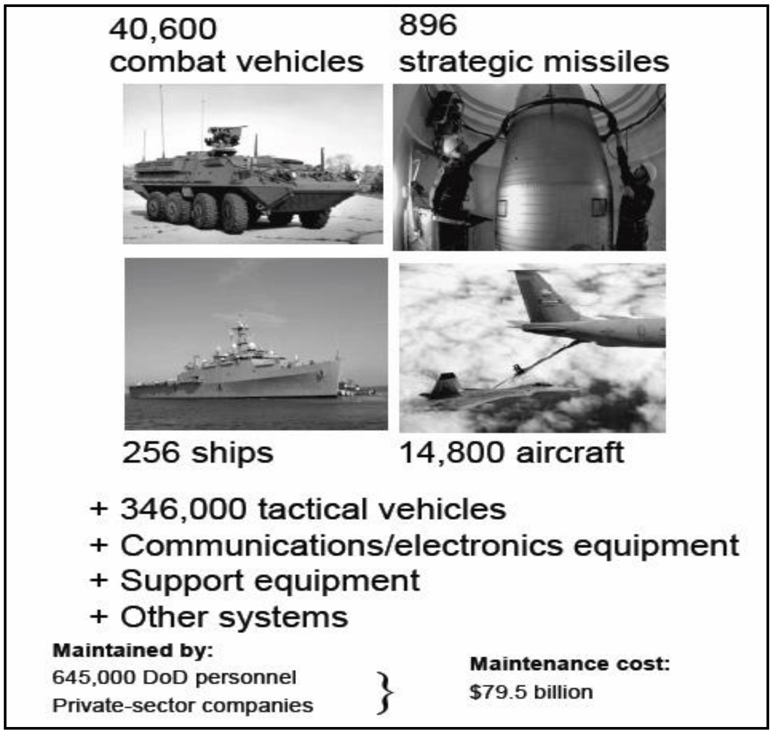

Figure 1. Systems Supported by DOD Maintenance
(OASD [L&MR], 2013, p. 3)

Performed at several levels, DOD materiel maintenance ranges in complexity from daily system inspections to rapid removal and replacement of components to complete overhauls or rebuilds of a weapon system. Levels of maintenance are largely distinguished largely by their relative capabilities, flexibility, agility, and capacity and are

- ***Depot***—the most complex and extensive work. This level of maintenance encompasses materiel maintenance requiring major repair, overhaul, or complete rebuilding of weapon systems, end items, parts, assemblies, and subassemblies; manufacture of parts; technical assistance; and testing. Each military service manages and operates its own organic depot-level maintenance infrastructure. The majority of depot maintenance, approximately three quarters, is associated with ships and aircraft; aircraft work amounts to more than half of the overall total while ship work accounts for about a third. The remaining work includes missile, combat vehicle, tactical vehicle, and other ground equipment system workloads.
- ***Intermediate***—less complex maintenance performed by operating unit back shops, base-wide activities, or consolidated regional facilities. Intermediate or shop-type work includes: limited repair of commodity-

oriented assemblies and end items (e.g., electronic “black boxes” and mechanical components); job shop, bay, and production line operations for special requirements; repair of subassemblies such as circuit boards; software maintenance; and fabrication or manufacture of repair parts, assemblies, and components.

- ***Organizational (or on-equipment)***—more time-sensitive work performed in the field, on the flight line, or at the equipment site. This type is normally performed by an operating unit on a day-to-day basis to support operations of its assigned weapon systems and equipment. It encompasses many categories, including inspections, servicing, handling, preventive maintenance, and corrective maintenance.
- ***Field***—signifies the combination of the organizational and intermediate levels. It comprises shop-type work as well as on-equipment maintenance activities at maintenance levels other than depot.

Ship Maintenance

In support of the Fleet Response Plan (Plan) that allows Fleet Commanders to control maintenance priorities in order to provide the right match of capabilities to requirements, the Navy’s organic ship maintenance program is performed by it’s public shipyards, regional maintenance centers, and intermediate maintenance facilities, in conjunction with private vendors and shipyards. Under the plan, fleets support the nation’s maritime strategy by quickly and efficiently allocating work to ships that are required to “provide sea control, forward presence and power projection in order to influence actions and activities both at sea and ashore.”

In addition, “the ship maintenance budget supports an integrated capabilities-based force through the maintenance and modernization of the right portfolio of ships to provide the optimum mix of force application and logistics ensuring ships are warfighting ready and well-maintained to operate forward.” For FY2015, the Navy requested $6.6 billion for total ship maintenance as shown in Table 1.

Table 1. Department of the Navy Ship Maintenance
(US Navy, 2014)

(Dollars in Millions)	FY2013	FY2014	FY2015
<u>Active Forces</u>			
Ship Maintenance	5,651	4,106	5,296
Depot Operations Support	1,157	1,275	1,339
Baseline Ship Maintenance (O&M,N)	6,808	5,381	6,635
Overseas Contingency Operations	1,287	2,679	-
Total Ship Maintenance (O&M,N)	8,095	8,060	6,635
Percentage of Projection Funded	100%	100%	80%
Annual Deferred Maintenance	-	-	1,341
Ship Maintenance Reset	-	-	582
CVN Refueling Overhauls (SCN)	1,723	1,855	54
% of SCN Estimates Funded	100%	100%	100%

Note 1: FY 2015 OCO request will be submitted at a later time to address deferred maintenance and ship maintenance reset.
Note 2: Totals may not add due to rounding.
Note 3: FY 2014 OCO includes Congressional directed

Navy Depot Maintenance Strategic Plan (2014–2019)

The Navy Depot Maintenance Strategic Plan (Maintenance Strategic Plan) was issued in October 2013 to realign resources and requirements to meet new national security challenges and to be prepared to maximize depot maintenance efficiency for a more technologically advanced force and to employ multiple options. The Maintenance Strategic Plan provides broad guidance for maintenance activities to deliver an exceptional mix of value to the war fighter, positively affecting readiness and operations. As a guide for decision makers, it provides flexibility to monitor progress against strategic goals that transform Navy's depot maintenance organizations for the future. The plan supports the war fighter through logistics transformation, core logistics capability assurance, workforce revitalization and careful capital investment.

Strategic goals set forth in the Maintenance Strategic Plan will transform the industrial enterprise into a flexible and dynamic partnership between Navy facilities, commercial suppliers, and other DOD depots. The mission is to provide a high state of readiness for combat-ready equipment in support of national security objectives and to sustain Navy Fleet readiness through effective maintenance and timely modernization of ships and aircraft. The vision for the Navy maintenance depots is a modern infrastructure and skilled workforce ready to meet the challenges of greater operational readiness and of maintaining new technologies and equipment that sharpen the Fleet's war fighting advantage against evolving threats.

The Navy currently utilizes both public and private depots to meet critical maintenance requirements with the same goal of increasing efficiency and effectiveness. Although all Navy SYSCOMs are concerned with maintenance activities, the two SYSCOMs primarily responsible for depot-level maintenance are as follows:

Naval Sea Systems Command (NAVSEA)

- Shipyards are the following: Portsmouth Naval Shipyard, ME; Norfolk Naval Shipyard, VA; Puget Sound Naval Shipyard and Intermediate Maintenance Facility, WA; and Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility, HI. These shipyards maintain, modernize, repair, and dispose of Navy ships and related components.

Naval Air Systems Command (NAVAIR)/Commander Fleet Readiness Centers (COMFRC)

- *Naval Aviation Fleet Readiness Centers.* Fleet Readiness Center East, Cherry Point, NC; Fleet Readiness Center Southeast, Jacksonville, FL; Fleet Readiness Center Mid-Atlantic, Oceana, VA; Fleet Readiness Center Southwest, North Island, CA; Fleet Readiness Center West, Lemoore, CA; Fleet Readiness Center Northwest, Whidbey Island, WA; Fleet Readiness Center Western Pacific, Atsugi, Japan and Fleet Readiness Center Aviation Support Equipment, Solomons Island, MD.

  Readiness Centers provide maintenance, repair and overhaul of aircraft, engines/modules, components, support equipment and services.

The Navy Depot Maintenance Strategic Plan provides an outline for implementing the strategic elements of the vision for the Navy's depots. The plan is organized around the following four strategic elements:

- Transform depots to align operations and metrics with war fighter outcomes
- Identify and sustain requisite core maintenance capabilities
- Develop and sustain a highly capable, mission-ready workforce

- Ensure adequate infrastructure to execute assigned maintenance workload

A number of metrics and assessment tools will be implemented to monitor the plan. The metrics were selected based on their ability to measure the progress of the detailed objectives. These metrics are a “recommended” set from which depots can select because there is no one set of metrics that addresses the wide-ranging activities of depot maintenance (i.e., ship, airplane, submarine, ground vehicle) conducted by the SYSCOMs. The Navy Depot Maintenance Strategic Plan is structured by logistics transformation, core logistics capability assurance, workforce revitalization and capital investment. Tables 2–5 show the goals, objectives, and metrics of each element.

Table 2. Logistics Transformation Goals and Objectives

Strategic Area 1: Logistics Transformation		
Goals	**Objectives**	**Metrics (Recommended)**
1. Ensure a fully optimized maintenance capability. • 1.1 Short-term: Ensure on-time delivery of ships, aircraft, engines and components to meet fleet entitlements for ready forces. • 1.2 Long-term: Reduce costs and cycle times while maintaining high standards of quality. • 1.3 Long-term: Reduce the depot maintenance component of Total Ownership Cost (TOC) on current and future systems. Strategy: The strategy to achieve logistics transformation is through: • Producing increased readiness and reduced repair cycle times through disciplined application of continuous process improvement techniques, leveraging the best value from within the Navy and commercial industry. (1.1) • Tailoring the infrastructure, logistics processes, and by employing a flexible labor force to maximize the worker on task time, minimize overhead costs and address the tightened budgetary environment. (1.2) • Alignment of acquisition and maintenance on systems by incorporating maintenance considerations in the acquisition process through a total system approach. (1.3)	1.1.1 and 1.2.1 Expand Continuous Process Improvement (CPI) methods and tools to reduce cycle times, address fiscal constraints and improve the efficiency, quality and responsiveness of operations. 1.2.2. Relocate functions within depots to more efficiently meet future requirements. 1.3.1 Early identification of maintenance requirements in the acquisition cycle to effectively plan lean, targeted logistics, maximizing existing infrastructure. 1.3.2 Platform life cycle maintenance engineering, maintenance and modernization planning, and management of maintenance strategies aligned to lower total ownership costs.	• M1: On-Time Delivery (OTD) Percentage (1.1.1) • M2: Ship/Unit Availability (Ao)/Loss Days (1.1.1) • M3: # Planned vs. Actual Mandays, DLHs (1.1.1) • M4: Cost, Schedule Variance (1.1.1) • M5: Function Consolidation and Rationalization (1.2.1, 1.2.2) • M6: Milestone Decision Authority Approvals (1.3.1, 1.3.2) • M7: Platform Planned Service Life (1.3.2) Assessment Tools: • CFRC Production Financial Report (PFR) (M1) • Loss Day Report (M2) • Depot Annual Workforce Assessment /Naval Shipyard Business Plan (M3, M4, M5) • CORE Report (M5) • PIA/IA (M5) • Fund 6 Report (M5) • Early Acquisition Lifecycle Depot Maintenance Planning Tool (ex. PIA/IA) (M6, M7) • Ship and Aircraft Supplementary Data Tables (SASDT)/ Aircraft Program Data File (APDF) (M7)

Table 3. Core Capabilities Assurance Goals and Objectives

Strategic Area 2: Core Capability Assurance		
Goals	**Objectives**	**Metrics (Recommended)**
2. Ensure sufficient public sector industrial capability is established and sustained in order to assure peacetime, surge, and wartime material readiness. • 2.1 Short-term: Maintain the proper balance between public sector and private sector depot maintenance workload. • 2.2 Long-term: Develop and maintain a ready and controlled source of depot-level maintenance and repair capability for current and new programs and future technologies. Strategy: The strategy to achieve public sector industrial capability assurance is: • To be sized (in terms of infrastructure) and shaped (in terms of capability) to support Naval readiness through organizational agility, flexibility, and proximity to the operating forces. (2.1) • To focus on schedule and quality through standardizing processes, sharing resources among public depots, and partnering with the private sector. (2.1) • To fund a sufficient workload at organic facilities to sustain the identified core capabilities. (2.1, 2.2) • To identify and sustain requisite core maintenance capabilities through a planning process that effectively estimates and monitors near and long term workload. (2.2) • To forge strong liaison between maintenance activities and the acquisition community to ensure that maintenance requirements and planning are in synch. (2.2)	2.1.1 Compliance w/ established Depot Source of Repair Decisions, DoD Instruction 4151.20, and legislative guidance (10 U.S.C. § 2366a/2366b, 2464, 2466, 2474, and 2476) 2.2.1 Increase interaction between maintenance community and acquisition community. 2.2.2 Identify core combat critical platforms prior to U.S.C. § 2366a Milestone A. 2.2.3 Identify critical skill/capability/capacity core related shortages within the public sector.	• M1:Current and Projected Public vs. Private Sector Ratios Trends (2.1.1) • M2: # of Core Capability Shortfalls (2.1.1, 2.2.1, 2.2.2, 2.2.3) • M3: # of Programs Achieving Compliance with U.S.C. § 2366a/2366b on First Pass (2.2.1, 2.2.2) • M4: Value ($) of Core Capability (2.2.3) Assessment Tools: • Annual 50/50 Reports (M1) • Biennial Core Reports (M2, M4) • 10 U.S.C. § 2366a/2366b Acquisition Milestones A & B Reports (M3)

Table 4. Workforce Revitalization Goals and Objectives

Strategic Area 3 : Workforce Revitalization		
Goals	**Objectives**	**Metrics (Recommended)**
3. To develop and sustain a highly capable, mission-ready workforce. • 3.1 Short-term: Replenish and develop human capital resources. • 3.2 Long-term: Driven by anticipated workload, shape the workforce to the right size with the right skill sets to meet future demand and accommodate workload fluctuation. • 3.3 Long-term: Increase labor efficiency to meet constrained fiscal environment. Strategy: The strategy to achieve workforce revitalization is: • By actively conducting workforce shaping via retention or, when necessary, attrition, minimizing adverse personnel actions. (3.1) • Through an integrated workforce plan that includes hiring, diversity goals, an apprentice program, standardized training, mentoring, leadership development and sharing critical skills across depots. (3.1, 3.2) • Plan for required future skills based on new platforms and the future force composition. (3.2) • Utilize Continuous Process Improvement/Lean Six Sigma labor focused projects to drive greater labor efficiency. (3.3)	3.1.1 Fill gaps in workforce through aggressive retraining initiatives with targeted hiring to maintain critical skills. 3.1.2 Reinforce the Labor-Management Councils efforts in collaborating on implementing and monitoring the revitalization plan. 3.2.1 Revitalization strategy incorporated in Independent Logistics Assessments (ILAs), including apprentice programs for long-term skill revitalization, hiring entry-level engineers and production personnel to rebalance grade distribution, workforce sharing for a more flexible workforce, and focused training and education of workers. 3.2.2 Optimize overtime to more efficient and effective levels of execution and budget for surge. 3.3.1 Reduce indirect costs and hour/task ratios.	• M1: Progress on Workforce Development Plan Milestones (3.1.1, 3.1.2) • M2: Workforce Age Demographics (3.2.1) • M3: # of Successful ILA Maintenance Planning Sections with CORE Identified (3.2.1) • M4: Overtime Ratio (3.2.2) • M5: Overhead Efficiency Ratio (Direct Labor/Total Labor) (3.3.1) Assessment Tools: • Depot Annual Workforce Assessment /Naval Shipyard Business Plan (M1, M2, M3, M4, M5) • Annual Workforce Age Demographic Report (M2, M5) • ILA Reports (M3) • 1397 Report (M5)

Table 5. Capital Investment Goals and Objectives

Strategic Area 4 : Capital Investment		
Goals	**Objectives**	**Metrics (Recommended)**
4. Ensure an adequate infrastructure to execute current and future workload. • 4.1 Short Term: Right size industrial capability to optimize for force structure projections by reducing outdated industrial equipment and achieving facility footprint reduction goals while improving safety. • 4.2 Long Term: Understand future fleet needs and maintenance strategies as they map to required investments to support core capabilities at both Depot and Intermediate maintenance locations. • 4.3 Long Term: realign IT resources and insert technology to streamline business processes, reduce IT costs, generate greater depot maintenance efficiency and improve data collection and analysis. Strategy: The strategy is to achieve effective capital investment is: • Invest in critical infrastructure to support depot-level operations and, ultimately, the war fighter and ongoing combat operations. (4.1) • Insure public sector core maintenance capabilities. (4.2) • Invest in industrial capacity to support cell manufacturing. (4.3) • Infusion of new technology to gain efficiency and capability. (4.3)	4.1.1 Invest in essential facilities to provide mission capability and capacity for current and future workload. 4.1.2 Create economies of scale through group buys of similar depot assets and procurement of commercially available standardized depot equipment. 4.2.1 Investment in sustainment technologies to keep pace with the latest industry standards. 4.2.2 Invest in infrastructure required to support future systems (UVs, cyber, 5th gen aircraft). 4.3.1 Consolidate current depot IT infrastructure into a net centric, shared data environment. 4.3.2 Network assets to optimize the workday and reduce maintenance costs (eTWD, RFID).	• M1: Capital Investment and Sustainment, Revitalization and Maintenance(SRM) levels relative to 6% floor (Title 10 USC 2476) (4.1.1) • M2: Facility Maintenance Backlog Trends (4.1.2) • M3: # of New Sustainment Technologies Implemented (4.2.1, 4.2.2) • M4: Function Consolidation and Rationalization (4.3.1) • M5: IT Roadmap with a Business Plan and Defined Milestones (4.3.1, 4.3.2) • M6: IT Cost Savings (4.3.2) Assessment Tools: • Fund 6 Report (M1, M2, M3, M4) • Annual Naval Shipyard Business Plan (M1, M5, M6) • Biennial Core Reports (M3) • Depot IT Strategic Plans (M5, M6)

Issues With Ship Maintenance

DOD cost-reduction imperatives have forced a review of ship maintenance and modernization tools and methods. The review has found that a particularly acute problem is how to acquire one-off (or few-off) parts. In ship maintenance, often the parts required were originally manufactured by now-defunct businesses. Often only one, or a few copies, of a given part is required for ship repair, maintenance, or improvement. Another challenge is the duration and cost of the traditional acquisition process when applied to parts, especially when old, unique, or few parts are needed. When outsourced, fabricating parts involves an extensive acquisition process in addition to reverse engineering and manufacturing the replacement parts. Acquiring just a few parts of a kind from organizations that are not the original equipment manufacturer (OEM), and sometimes from the OEM, tends to take longer and cost more than acquiring many copies of a currently manufactured part. Manufacturing small numbers of parts such as customized or obsolete components can be very expensive. The loss of the small- and medium-size industrial base to support ship maintenance and upgrades leads to very expensive manufacturing of custom parts; hence, the proverbial $1,000 bolt. In addition, in the current manufacturing base, custom parts are very expensive to design and produce in job shops using traditional methods. Also, engineering design changes balloon the costs of projects by creating large numbers of customized parts or modifications of existing parts.

Drew, McGarvey, and Buryk (2013) of the Rand Corporation studied make/buy decisions by the U.S. Air Force. They describe parts with two parameters; how frequently the part is needed (frequency) and the asset specificity (uniqueness). Their analysis identified specific types of aircraft maintenance work (e.g., penetrating aids, fire control, and propulsion) that are currently being performed externally but might be better performed by the U.S. Air Force. Given the fast evolution of manufacturing technologies, similar studies are needed that include the impacts of the adoption and use of new technologies on DOD make/buy decisions.

The manufacturing of some types of parts by Navy personnel using new technologies, such as 3DLST for the reverse engineering, 3DP for the fabrication and manufacturing of the parts, and CPLM for managing the information, may be able to generate substantial savings. Whether to outsource or in-source manufacturing using new technologies is a trade-off that must be investigated to determine the relative benefits of each.

Problem Description

Issues in the Use of 3DLST and 3DP in Ship Maintenance and Upgrading

Commercially available new technologies such as 3DLST and additive manufacturing (AM), can improve ship maintenance and modernization. They can be used to improve the distant support of the fleet. The website of the NAVSEA distance support operations at Port Hueneme provides an example of the benefits of distance support and the potential benefits of 3DLST and 3DP:

Resolving Problems at Sea, from Shore

> It is 0700 (7:00 am) and a Navy destroyer, underway in the Persian Gulf, has a problem with its primary radar system. The radar technician has run all the appropriate equipment tests, but is still unable to pinpoint the fault. Political unrest means that tensions are high in the

> area and the ship may be called into action at any time. The radar problem needs to be resolved, and quickly.
>
> The technician calls upon experts at Navy Shore Command for support. On the other side of the world, engineers use a Navy Distance Support Web Portal to research all the engineering and historical information needed to understand the problem. They are able to connect to the ship's system and remotely run system tests.
>
> Within minutes they have monitored the system's performance, analyzed test results, and isolated the faulty component. The part is replaced from onboard spare parts or spares from another ship in the battle group. The ship is once again mission-ready, without ever having left its designated battle arena. (NSWC, 2013)

Notice that, in this scenario, "The part is replaced from onboard spare parts or spares from another ship in the battle group." This solution may not be available if the part required is not in the fleet's inventory, is a custom part, is an obsolete part, or must be customized to fit specific conditions. In these cases the part must be provided from a shore inventory, if it is available, or redesigned, then fabricated, and then manufactured. New technologies can facilitate accomplishing these tasks quickly and without excess costs.

Issues Related to Costs

In a 2013 report on U.S. Air Force sourcing titled "Enabling Early Sustainment Decisions, Application to F-35 Depot-Level Maintenance," Drew, McGarvey, and Buryk (2013) of the Rand Corporation proposed and applied a method for recommending sourcing with two dimensions: *frequency* of need and asset *specificity* (Figure 1). In this framework, "OEM" (upper left in Figure 2) is outsourcing to the original equipment manufacturer, "Organic" (upper right in Figure 2) is in-sourcing by the U.S. military, "Spot-market contract" (lower left in Figure 2) is outsourcing for one or a few of a single part type, and "Longer-term contract" (lower right in Figure 2) is long-term outsourcing to (often) a different private manufacturer for many parts.

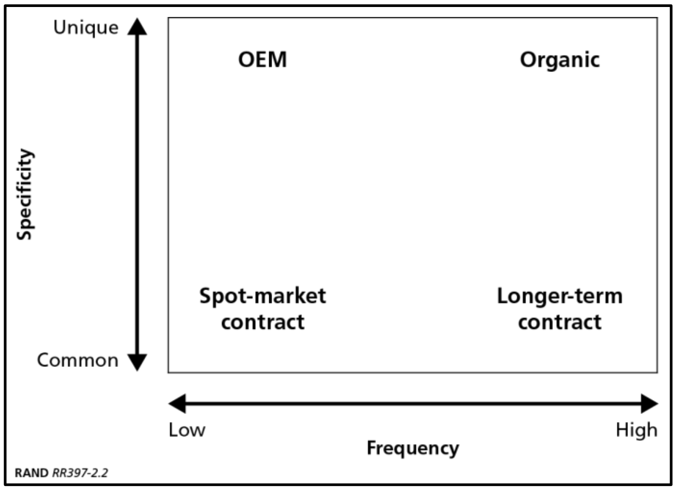

Figure 2. A Conceptual Sourcing Framework
(Drew, McGarvey, & Buryk, 2013)

The Rand study says, in part,

> A unique activity that occurs frequently would be something that the Air Force would want to perform with organic assets [i.e., in-source]. That is to say, if an activity is unique and the organization requires it frequently, no external provider could capture a greater economy of scale than the Air Force (due to its uniqueness), and performing it in-house should yield a higher return on investment (due to high frequency). However, as that frequency declines and if the activity remains unique, it may be difficult for the Air Force to capture any return on investment for capital setup costs. (p. 9)

The kinds of parts replacement studied in the current work are primarily unique and few in frequency (often only one breaks and requires replacement, rarely many). The Air Force sourcing solution is to use spot-market contracts (i.e., buy from any qualified supplier) if the part is relatively simple or to outsource to the OEM if the part is complex.

Although the Rand study does not address the adoption and use of new manufacturing and product management technologies, the framework can be used to describe how the adoption of the new technologies can change sourcing. The Rand study identifies the military's difficulty in capturing return on investment (ROI) due to the capital setup costs as the reason in-sourcing is not feasible for few parts. The technologies that the current work focuses on can greatly decrease (by orders of magnitude) the setup costs of making parts, thereby increasing the in-sourcing ROI and making in-sourcing more attractive. This effectively shifts the optimal sourcing of some parts from the left side of Figure 2 to the upper right corner of Figure 2. The current work expands on this conceptual shift by quantifying the potential savings of shifting some parts from outsourcing to in-sourcing.

3DLST and 3DP have the potential to generate large cost savings by, for example,

- Reducing labor and material costs by reducing wasted material required by traditional manufacturing methods.
- Reducing manufacturing costs by eliminating the need for traditional manufacturing equipment such as large lathes and drill presses.
- Reducing or eliminating parts inventories and the infrastructures required to maintain those inventories by making parts on demand.
- Reducing the space needed on ships to carry inventories and fabricating equipment.

However, it is not clear whether the Navy will capture the potential savings if new technologies are outsourced to private industry, which has historical design and manufacturing costs as a benchmark and traditional manufacturing infrastructure costs. More savings may accrue if the new technologies are adopted and these operations performed by Navy organizations. However, building these internal capabilities, skilled workforce, and capacity will require an initial investment. A cost comparison of outsourcing versus in-sourcing fleet maintenance and upgrading operations with new technologies can provide insight for developing a technology adoption strategy.

Current research has investigated the adoption of the 3DLST, 3DP, and CPLM technologies for fleet maintenance and modernization. A critical implementation issue is whether to develop 3DLST, 3DP, and CPLM capabilities within the service (i.e., in-sourcing) or to have industry do this for the Navy (i.e., outsourcing). This study creates the needed make/buy comparison for implementing 3DLST, 3DP, and CPLM. The work addresses these important issues by investigating the following questions:

1. What are the relative costs of in-sourcing 3DLST, 3DP, and CPLM fleet maintenance and modernization compared to outsourcing those same operations with contractors using these technologies?
2. What cost savings may be captured by the use of 3DLST, 3DP, and CPLM for fleet maintenance and modernization if those operations are insourced?

Background

The federal government has debated the in-sourcing and outsourcing issue for decades. This section provides an introduction to outsourcing and in-sourcing issues at the federal level, focusing on workforce sourcing issues. It provides a brief history of in-sourcing, rationale for in-sourcing and examples of successful in-sourcing initiatives.

The Congressional Research Services defines *outsourcing* as a decision by the government to purchase goods and services from sources outside the affected government agency. Outsourcing ranges from commercial services such as trash removal to non-commercial services. Federal sourcing policy dating back to the 1950s has generally focused on the premise that the government should rely on the private sector for the provision of certain goods and services (Halchin 2012). It has also provided guidance for conducting public-private competitions to determine whether federal employees or contractors should be selected to perform certain agency functions.

Three Bureau of the Budget (BOB) bulletins issued in the 1950s encourage the government to rely on the private sector for goods and services (Halchin, 2012). Certain functions performed by federal employees may be subject to public-private competition to determine whether the incumbent workforce continues to perform the work or the agency awards a contract to a private company. Circular A-76, initially issued in 1966, continued governmental reliance on the private sector while providing guidance and procedures for carrying out public-private competitions. Five revisions have been made to Circular A-76 by the Office of Management and Budget from 1966 to 2012.

Actions have been undertaken by several Congresses and the Obama Administration to promote "in-sourcing," or the use of government personnel to perform functions that contractors have performed on behalf of federal agencies. For example, the 109th through the 111th Congresses enacted statutes requiring the development of policies and guidelines to ensure that agencies "consider" using government employees to perform functions previously performed by contractors and any new functions. The Obama Administration has vigorously promoted in-sourcing with officials calling for consideration of in-sourcing in various workforce management initiatives.

The 109th Congress enacted legislation directing the Secretary of Defense to prescribe guidelines and procedures to ensure that Federal Government employees are considered for all current or future current work performed under DOD contracts. The National Defense Authorization Act for FY2006 issues guidelines and procedures to ensure that “special consideration” is given to using government personnel to perform functions that

- had been performed by government employees at any time on or after October 1, 1980;
- are closely associated with the performance of inherently governmental functions;
- are performed under contracts that were not competitively awarded; or have been performed poorly by a contractor due to excessive costs or inferior quality (GAO, 2012).

Subsequent Congresses expanded upon these requirements. The National Defense Authorization Act for Fiscal Year 2008 (NDAA 2008) revised guidelines and procedures for using civilian employees to perform DOD functions. NDAA 2008 also implemented guidelines and procedures to ensure consideration was given to using DOD civilian employees to perform new functions on a regular basis. NDAA 2008 also provided that DOD may not conduct a public-private competition prior to in-sourcing such functions; added a new section describing the functions that were to receive special consideration from DOD when considering the use of DOD civilian employees; and required special consideration be given to a new requirement similar to a function previously performed by DOD civilian employees or is a function closely associated with the performance of an inherently governmental function (GAO, 2012)

The DOD issued in-sourcing guidance in April 2008 and May 2009 to assist components in implementing legislative actions. According to the May 2009 guidance, DOD components should first confirm that a particular mission requirement is still valid and enduring—that DOD will have a continued need for the service being performed. If the requirement is still valid, the component should consider in-sourcing the function. If the component determined that the function under review was inherently governmental or exempt from private sector performance no cost analysis was required. Rationales to in-source include the following under the May 2009 in-sourcing guidance:

- Function is exempt from private sector performance to support the readiness or workforce management needs of DOD. According to DOD’s policy for determining the appropriate mix of military, DOD civilians, and contractor support, a function could be exempt from private sector performance for a variety of reasons, including functions exempt for career progression reasons, continuity of infrastructure operations, and mitigation of operational risk.

- Contract is for unauthorized personal services. Special authorization is required for DOD to engage in personal services contracts, which create a direct employer/employee relationship between the government and the contractor’s personnel.
- Problems with contract administration resulting from insufficiently trained and inexperienced officials available to manage and oversee the contract.

The Secretary of Defense announced in April 2009 his intent to reduce the department’s reliance on contractors through in-sourcing, stating that the department’s goal was to hire as many as 13,000 new civil servants in fiscal year 2010 to replace contractors and up to 30,000 new civil servants in place of contractors over a 5-year period.

In January 2013, the Private Sector Notification Requirements in Support of In-sourcing Actions memorandum was issued. This memorandum provides instructions regarding the notification of contractors when making a determination to in-source. The guidance supplements existing policies related to in-sourcing under the National Defense Authorization Act for Fiscal Year 2012 (Appendix 1 is the complete memorandum.) The guidance outlined three categories for justifying in-sourcing of contracted services:

- *Inherently Governmental Functions*: Consistent with statutes and policy, immediate action to in-source (or divest) work performed under contract that is determined to be inherently governmental.
- *Work Closely Associated with Inherently Governmental Functions*: Some work, while not inherently governmental (including many non-inherently governmental acquisition functions), may not be appropriate for continued performance by the private sector (i.e., risk mitigation, operational continuity, maintain readiness). Under certain circumstances, increased management control and oversight of such work, modifications to the statement of work or changes to how services are performed may be appropriate in lieu of in-sourcing.
- *Cost-Based In-sourcing Decisions*: Contracted services may be in-sourced if the work is determined to be cost effectively delivered by civilians.

Figure 3 is a time line of key in-sourcing events at the DOD from 2006 to 2011.

Figure 3. Time Line of Selected In-Sourcing Events
(GAO, 2012, p. 9)

Decisions to in-source by DOD military services, agencies, and components were to be based on a series of choices, as shown in Figure 4 (Williams, 2011).

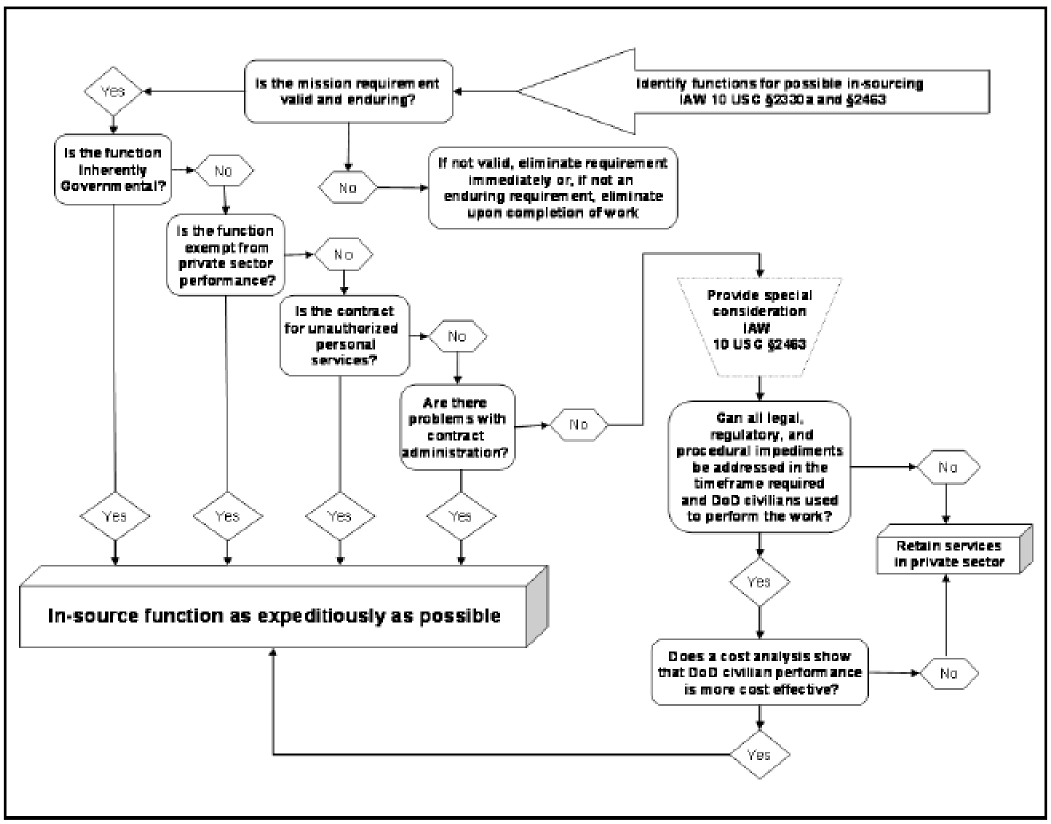

Figure 4. DOD In-Sourcing Tree
(Williams, 2011)

Figure 5 shows examples of proposed in-sourcing initiatives from 2010 and 2011 along with reasons cited.

1) **Agency:** Air Force
Contract Number: FA8623-05-C-6350
Scope of Work: Operations and Maintenance, Guard Services, Airfield Operations, Fire Fighting (Structural and Aircraft Rescue), Engineering, Aircraft Fueling, Maintenance, IT, Grounds and Janitorial, Vehicle Maintenance at Plant 42, Palmdale, California.
Insourcing Rationale: Cost savings.

2) **Agency:** Air Force
Contract Number: FA4890-10-C-0006
Scope of Work: Meteorology Services (weather forecasting, weather observation, maintenance and support services) at 11 Army Bases Nationwide.
Reason Stated for Insourcing: Cost savings.

3) **Agency:** Air Force
Contract Number: FA3002-04-C-0005
Scope of Work: Pilot Training at Pensacola Naval Air Station, Florida.
Insourcing Rationale: Cost savings.

4) **Agency:** Army
Contract Number: NAFIB9-08-C-0023
Scope of Work: Library Administrative Support at Fort Polk, Louisiana.
Insourcing Rationale: Cost savings.

5) **Agency:** Army
Contract Number: W911SE-07-G-0001-0001
Scope of Work: Helpdesk, Engineering Network, System Security, Mail Administration Support at Ft. McPherson, Georgia.
Insourcing Rationale: Cost savings.

6) **Agency:** Army
Contract Number: W911SE-08-C-0023
Scope of Work: Program Management for the Command's Antiterrorism/Force Protection Program at Ft. McPherson, Georgia.
Insourcing Rationale: Cost savings.

7) **Agency:** Army
Contract Number: W911SE-07-D-0035-0002
Scope of Work: All Personnel, Supplies, Administration, and Management to Operate the G3 Force Management Division (FMD) Mission at AERCENT Headquarters, Fort McPherson, Georgia and Kuwait.
Insourcing Rational: Cost savings.

8) **Agency:** Army
Contract Number: W911SE-07-D-0024-0002
Scope of Work: Military Vehicle Condition Evaluations at Ft. McPherson, Georgia.
Insourcing Rational: None.

Figure 5. Examples of In-Sourcing Initiatives
(BCFC, 2011)

(Figure 5 [continued]: Examples of In-Sourcing Initiatives [BCFC, 2011])

10) **Agency:** Army
Contract Number: W81K00-09-P-0314
Scope of Work: Non-personal Services to Provide Outpatient Clinical Coding, Physician Documentation Training, and Auditing of Written and Computerized Medical Records at Raymond W. Bliss Army Health Center (RWBAHC) and Its Clinics Located within the Health Center and at Primary Health Care Sites on the Fort Huachuca Installation at Fort Sam Houston, Texas.
Insourcing Rationale: None.

11) **Agency:** Army
Contract Number: W911SO-09-P-ORI-01
Scope of Work: Providing U.S. Army Students the Specialty Skills and Technical Ability to Perform the Duties of a Motor Vehicle Operator (otherwise known as Motor Transporter) of Light and Medium Tactical Wheeled Vehicles under Varying Field Conditions and Convoy Operations at Fort Leonard Wood, Missouri.
Insourcing Rationale: None.

12) **Agency:** Army
Contract Number: W911KF-08-C-0008
Scope of Work: Production Supply Support including Material Handling, Fuel Distribution, Tire Repair, and Disassembly and Assembly Support at Anniston Army Depot, Alabama.
Insourcing Rationale: None.

13) **Agency:** Army
Contract Number: W911KF-06-C-0001
Scope of Work: Production Cleaning including Steam Cleaning, Vehicle Cleaning, and Container Cleaning at Anniston Army Depot, Alabama.
Insourcing Rationale: None.

14) **Agency:** Army
Contract Number: W81K00-07-P-0950
Scope of Work: Perform Medical Support Assistant Services, (also known as a Medical Clerk) at the Medical Treatment Facility (MTF), Raymond W. Bliss Army Health Center (RWBAHC), Fort Huachuca, Arizona.
Insourcing Rationale: None.

15) **Agency:** Army
Contract Number: W81K00-06-P-0731
Scope of Work: Provide the Services of a Clinical Psychiatric Nurse to the Institute of Surgical Research Burn Center at Brooke Army Medical Center, Fort Sam Houston, Texas.
Insourcing Rationale: None.

16) **Agency:** Air Force
Contract Number: FA9301-09-R-0007, Order 0001
Scope of Work: Photography and AV Services at Edwards Air Force Base, California.
Insourcing Rationale: Cost savings.

17) **Agency:** Air Force
Contract Number: FA663308D0002

(Figure 5 [continued]: Examples of In-Sourcing Initiatives [BCFC, 2011])

19) **Agency**: Coast Guard
Contract Number: HSCG23-08-D-MMZ339
Scope of Work: Contract supports function of licensing merchant mariners at the Coast Guard's National Maritime Center in West Virginia.
Insourcing Rationale: Cost savings.

20) **Agency:** Air Force
Contract Number: FA8771-04-D-0003 TO QW02
Scope of Work: 30SW GeoBase (IGI&S) Support at Vandenberg AFB, California.
Insourcing Rationale: Cost Savings.

21) **Agency:** Air Force
Contract Number: GS-35F-0425P/GST0509BM0062
Scope of Work: Installation and Expeditionary Geospatial Information & Services Program Sustainment and Support, 6 AFMC Installations.
Insourcing Rationale: Cost Savings.

22) **Agency:** Air Force
Contract Number: GS-35F-0425P / GST0509BM0111
Scope of Work: Program Support for Communications Mission Data Sets with Cyberspace Infrastructure Planning System (CIPS) Visualization Component, Various AMC Installations.
Insourcing Rationale: Cost Savings.

The DOD reported that nearly 17,000 newly created civilian authorizations resulted from in-sourcing actions in fiscal year 2010. As seen in Figure 6, 42% of the new authorizations were established in the Army; 28% in the Air Force; 16% in the Department of the Navy (including the Marine Corps); and 14% in other DOD agencies.

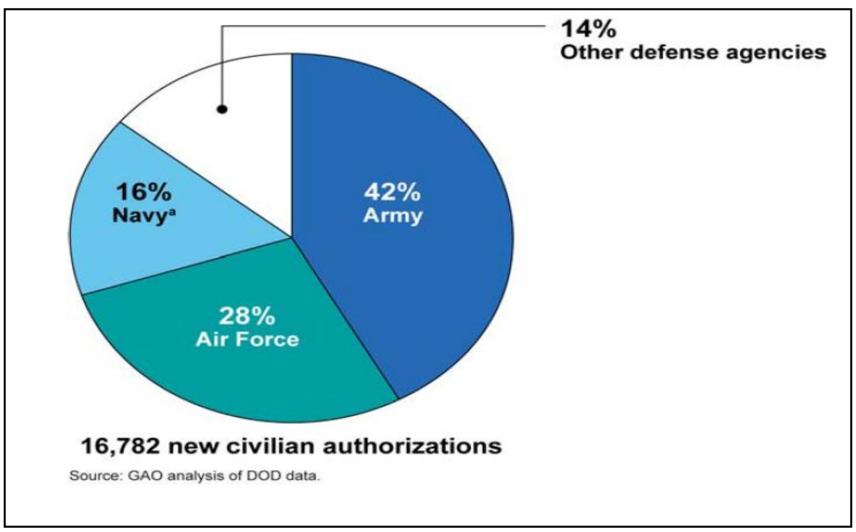

Figure 6. Distribution of Total DOD In-Sourcing Actions for Fiscal Year 2010
(GAO, 2012, p. 11)

For half of the actions, driving in-sourcing decisions was the determination that the function would be more cost effective if performed by DOD civilian employees. Figure 7 breaks down the reasons for in-sourcing while Figure 8 lists the reasons cited by Army, Navy, Marine Corps and Air Force. The Air Force and Marine Corps based in-sourcing decisions entirely on costs while the Army and Navy based its decisions on the criteria of being exempt from private sector performance. Differing rationale behind in-sourcing decisions by the military services were partly due to differing objectives. Interviews with Air Force and Marine Corps command officials indicated that their objective was to realize cost savings from in-sourcing to comply with budget reductions associated with the DOD Comptroller's April 2009 budget decision, which reduced funds from contracted services and placed a portion of those funds in civilian authorizations accounts (GAO, 2012). Alternatively, Naval Sea Systems Command officials pursued in-sourcing processes based on analysis the command had performed of weaknesses in its internal capabilities and over-reliance on contractors. This analysis resulted in categorizing the command's in-sourcing actions as exempt from private sector performance for career progression reasons.

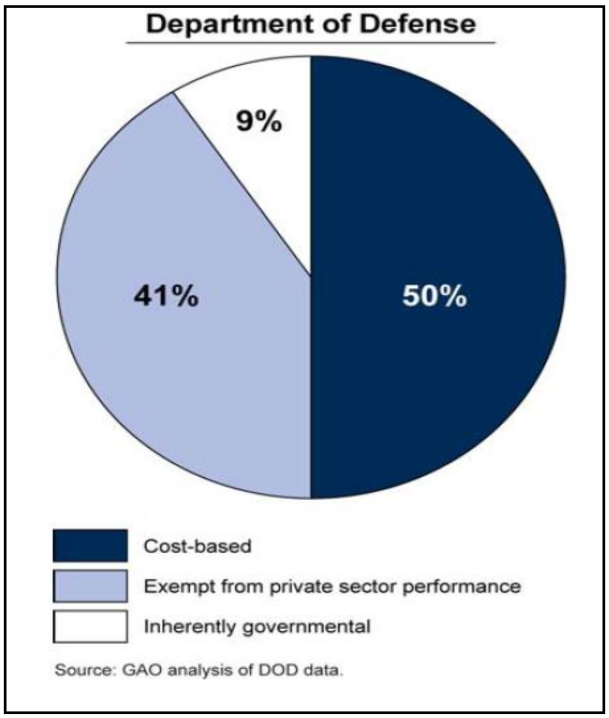

Figure 7. Reasons DOD Cited for Its Fiscal Year 2010 In-Sourcing Decisions
(GAO, 2012, p. 12)

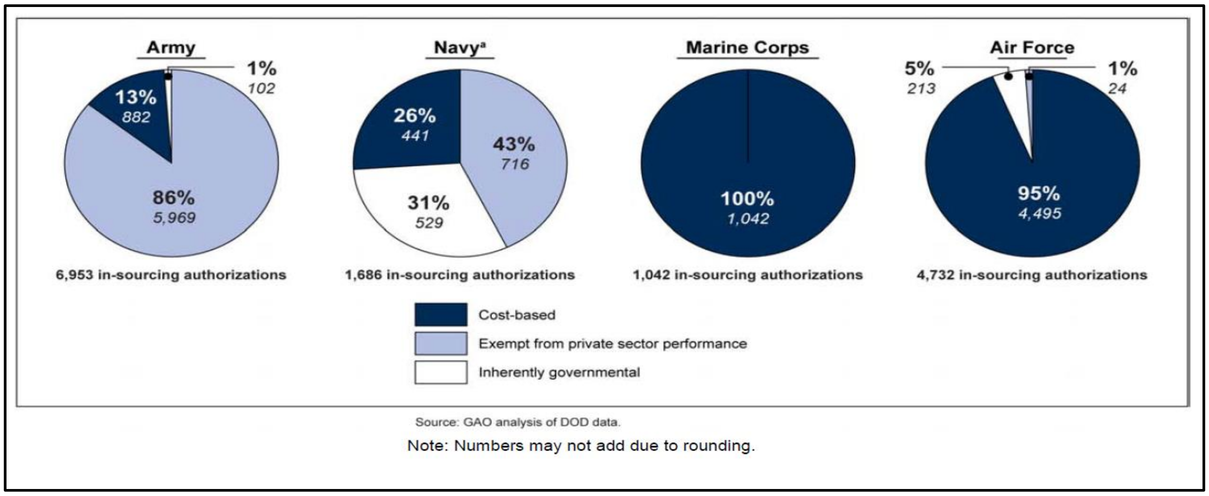

Figure 8. Reasons Cited by the Military Services
(GAO, 2012, p. 12)

Legal Challenges

In-sourcing initiatives of Congress and the Obama Administration have generated much controversy and have resulted in legal challenges of agencies' determinations to in-source particular functions. Numerous lawsuits have been filed since 2008 questioning broader issues such as whether agencies' implementation of in-sourcing conflicts with civil service, ethics, or small business laws. Contractors have also claimed that the DOD's costing methodology does not account for a multitude of in-house costs.

Many of the challenges by contractors to DOD in-sourcing decisions have been lodged before the Court of Federal Claims (COFC) under the Tucker Act (28 USC § 1491) with minimal success (Ganderson, 2014). In one of the latest challenges, *Fisher-Cal Industries, Inc. v. United States* (April 8, 2014), the Court of Appeals for the DC Circuit made a decision. Appealing the District Court's decision, Fisher-Cal had argued that the Air Force violated the Administrative Procedures Act when it decided to in-source the parties' contract instead of renewing it. The Air Force failed to perform a proper cost comparison analysis under 10 USC §§ 129a and 2463 (Ganderson, 2014). The DC Circuit affirmed the lower court's dismissal of the claim for lack of jurisdiction. Following the Federal Circuit's lead, the DC Circuit found that the COFC has exclusive jurisdiction under the Tucker Act to entertain an in-sourcing challenge because it fits within the definition of a "procurement" under 28 USC § 1491(b). (Ganderson, 2014).

Advantages and Disadvantages to Outsourcing

Despite the legal challenges, DOD officials report that, "In-sourcing has been, and continues to be, a very effective tool for the Department to rebalance the workforce, realign inherently governmental and other critical work to government performance, and in many instances to generate resource efficiencies" (GAO, 2012). Beyond workforce realignment, in-sourcing offers additional advantages of cost savings and increased efficiencies. Table 6 identifies advantages and disadvantages to outsourcing for the DOD.

Table 6. Advantages and Disadvantages of Outsourcing for DOD
(Marquis 2011, p. 9)

Advantages of Outsourcing	Disadvantages of Outsourcing
Allows DoD to focus on core competencies	Contractors traditionally provided too little documentation/lessons learned/knowledge transfer in past
Private industry competition increases efficiency and decreases costs	When contracts end, often so does the product specific knowledge and maintenance can be costly
Paradigm shift to insourcing will be organizationally expensive	Can lead to loss or atrophy of DoD organic employee technical skill set
Private industry covers the cost of continuous IT training; free to DoD	Perceived loss of control of effort
Allows for flexibility in personnel ramp-ups and downs resulting in cost savings for project and long-term workforce	Accountability: contractors are accountable to their companies, not the DoD or the effort
Usually lower cost alternative	IT efforts appear pricey at first glance!
Access to economies of scale	Many IT efforts have been mismanaged, leading critics to question outsourcing as fault
Access to private industry allows for partnership on innovation and use of proven, best business practices	When over-performed, can deplete the DoD organic workforce talent
Lowers DoD's fixed costs	The timing of insourcing effort coincides with large workforce retirement-hiring - needs could be much more than expected
Industry can retain talent better with better job category and salary structures for IT jobs	Acquisition issues: DoD cannot pick the precise people to work effort - success is about having the right people work the effort at the right time
Private industry already has the people on-board.	Success requires strong leadership and well-defined requirements, which are often hard to obtain
Have requisite talent & experience to deploy solution faster	Can be risky when not poorly contracted and managed
Helps private industry and the U.S. economy	

Successful In-Sourcing Examples

The literature reviewed several examples of federal agencies successfully bringing projects back in-house. Examples include the following:

- Fleet and Industrial Supply Center (FISC) Puget Sound, Bremerton, WA, completed the first Navy conversion of contract operations to government work in 2009, saving the Navy $2.7 million over five years. According to FISC Puget Sound's director of Business Support, conversion of the logistics contract to in-house performance decreased costs while increasing the effectiveness of supply chain management. In addition, the transition plan provided three key benefits: it minimized the impact on customer support, permitted the contractor to reduce staffing without adverse action, and permitted the contract employees to apply for civil service positions.

- Federal Aviation Association (FAA) Tech Center in-sourcing saves between $52 and $203 million in data system costs over the life of the project. Prior to the new NADIN Message Switch Rehost (NMR), the FAA used a National Airspace Data Interchange Network (NADIN) to exchange critical information. Customers of the network included FAA National Airspace System, Department of Interior, National Weather Service, DOD, Department of Homeland Security, commercial airlines, the general aviation community, and airline data service providers. The network was a significant part of the global International Civil Aviation Organization (ICAO) Aeronautical Fixed Telecommunications Network of 245 communications centers in 189 countries and 26 international AFTN communication centers around the world.

  Completed in 2009, the replacement process required seamless migration of over 2,000 domestic and international users to the new system. The in-house team was responsible for all phases of the project development lifecycle (requirements definition through design, software development, hardware integration, documentation, test & evaluation, deployment, and training). Estimates from external contractors to replace the system ranged from $90 million to $240 million over a 10-year service life. The decision to in-source the effort was based on best cost, technical approach and least risk (USDT, 2009).

- The Army claimed that in-sourcing resulted in savings of 16% to 30% and that in-sourcing was largely responsible for reducing the Army's contract services obligations from $51 billion in 2008 to $36 billion in 2010 (Aronowitz, 2012).
- The information technology division of U.S. Customs and Border Protection at the Department of Homeland Security estimated that it saved $27 million in 2010 out of a budget of $400 million by taking 200 private contractors and giving those same individuals government jobs (Lipowicz, 2011).

In addition, the Internal Revenue Service abandoned experiments with outsourcing debt collection after the agency calculated that contractors brought in less revenue than federal employees (GAO, 1997).

In-Sourcing Uncertain Future

The Secretary of Defense announced in August 2010 that the Pentagon was implementing a fiscal 2011 billet freeze and halting its in-sourcing plans because of a lack of cost savings. The plan affected only civilian agencies and offices; the military services were exempt from the freeze, thus allowing them to continue with in-sourcing plans. The Army, one of the earliest proponents of in-sourcing, also retreated in 2011 when it halted its in-sourcing initiatives. (Brodsky, 2011). Furthermore, the American Federation of Government Employees (AFGE) has stated that the DOD has essentially stopped in-sourcing initiatives (AFGE, 2014).

Additive Manufacturing, Collaborative Product Lifecycle Management and 3 Dimensional Laser Scanning Technologies

This section introduces additive manufacturing, product lifecyle management, and 3 Dimensional laser scanning technologies. It begins with a discussion of additive manufacturing, also commonly referred to as 3 dimensional scanning, one of the most promising technologies.

Additive Manufacturing

Additive manufacturing (AM) is the youngest and most diverse technology addressed in this research. AM has quickly moved through technology development into the mainstream, with websites now offering services that allow the public to design and use AM to produce products of their own design (e.g., see Kronsberg, 2013).

The following descriptions, based primarily on Gibson, Rosen, and Stucker (2010) and Lipson and Kurman (2013), first describe the principles and techniques, followed by an overview of the potential market size of 3D technology. Also included in this section are potential adoption rates and applications of the technology. Finally, a comparison of conventional manufacturing to specific AM technologies is provided.

Principles and Techniques

Additive manufacturing is defined by the American National Standards Institute as the "process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. Synonyms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing and freeform fabrication" (Wohlers, 2013). 3D printing is also another common synonym.

AM differs radically from the currently dominant manufacturing methodologies. Most current methods use subtractive processes (e.g., machining), but AM builds a 3D object by gradually adding successive layers of material that are laid down exactly in their final location. AM does this by fabricating objects directly from 3D computer-aided design (3D CAD) models. The 3D model is disaggregated into multiple horizontal layers, each of which is produced by the machine and added to the preceding layers.

AM generally involves a number of steps that move from a virtual 3D CAD model to a physical 3D object, as follows:

- **CAD:** A 3D CAD model of the target object is built in software. The 3D CAD model determines only the geometry of the target object. 3D laser scanning can be used to create the model.
- **Conversion to Stereolithography STL files:** The CAD model cannot be used directly by AM machines; it must be converted to STL format. An STL file describes the external closed surfaces of the original CAD model and forms a basis for calculation of layers. The STL model approximates surfaces of the model with a series of triangular facets.
- **Revision of STL File:** STL files must often be manipulated before manufacturing. For example, multiple objects may be manufactured simultaneously from the same file, requiring that the STL files of the objects be integrated.
- **Machine Setup:** AM machines must be set up to accommodate specific materials, layer thicknesses, and timing.
- **Build:** Although all AM machines follow the layer-by-layer fabrication process, they utilize different techniques and technologies. For example, some of them use a high-power laser beam to melt a very fine metal powder in order to form a thin layer, while some others use UV light to solidify a specific kind of liquid polymer, called photopolymer.
- **Post-Process:** Post-processing may be required due to the need to cure photopolymers.

Additive Manufacturing vs. Conventional Manufacturing Methods

Additive manufacturing is occasionally referred to as rapid prototyping, with *rapid* in this context referring to the whole process of designing, manufacturing, modeling, and testing not merely the manufacturing process itself.[1] AM seeks to minimize intermediate steps and streamline the manufacturing process. Other related technologies such as 3DLST and CPLM can be used to facilitate these improvements. In contrast to the conventional manufacturing practice of producing different parts and then combining them to create a final part, AM provides the opportunity to make the final part as whole, regardless of the number of its components and complexity of their connections. In addition, design changes are relatively easy with AM. For example, if casting or injection methods are used to make a product, small changes in design can require discarding the mold and building a new one. By simplifying the manufacturing process, AM decreases the time required to change the design and thereby to generate the part, as well as the amount of required resources.

One of the greatest advantages of AM is the freedom it provides for designers. The more complex the design, the more advantage can be gained by using AM. A related advantage of AM is its accuracy. AM processes can operate with resolution of a few tens of microns. In other words, AM machines can produce layers as thin as the diameter of human hair. Figure 9 illustrates a microscale AM product.

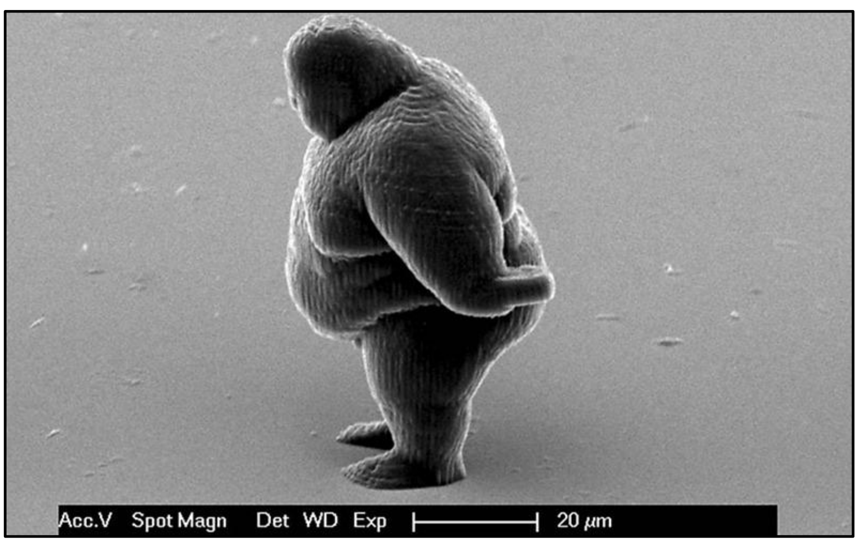

Figure 9. Fat Man, a Microscale AM Product
(Reuters, 2013)

[1] For example, high-speed computer numerical control (CNC) machines work much faster than AM machines.

AM also has limitations. A primary limitation concerns the materials that can be used. AM technologies were originally developed around polymer materials. Then materials such as metals were introduced. The current approach remains limited to a range of materials and their physical properties (e.g., strength). Some AM materials require careful handling. They usually have a limited shelf life and must be kept in conditions that prevent unwanted chemical reactions. Exposure to moisture, excessive light, and so forth may degrade or destroy some materials.

Additive Manufacturing Methods

Although all AM methods use layer-by-layer production, they differ in terms of procedures, technologies, materials, and applications.

- **Photopolymerization:** Photopolymerization solidifies a special type of liquid polymer using UV light. Stereolithography (SL or SLA) is a well-known photopolymerization technique. In SL, a vat of liquid photopolymer sits in an AM machine. A UV light source above the vat emits a narrow beam of light. Once the UV beam touches the photopolymer, the liquid hardens. A computer-controlled table in the vat of liquid moves up and down. Initially the table is just slightly lower than the liquid surface, allowing a very thin layer of liquid to cover it. The UV beam sweeps the liquid surface and touches target points of the lowest layer of the final object in the CAD model. The moving table (with the first layer stuck on it) lowers slightly (the thickness of a layer) into the liquid polymer, allowing a film of polymer to cover the first solid layer. This process is repeated with each sweep of the surface, layering the object until the whole is fabricated. Photopolymerization can also use visible lights or other radiations, depending on the photopolymer's properties.
- **Powder Bed Fusion:** Powder bed fusion (PBF), also widely referred to as selective laser sintering (SLS), is similar to SL in terms of procedure, but uses steel powder materials (instead of liquid polymer) and a heating source, usually a high-power laser (instead of UV light). As the first step, a roller brushes a thin layer of powder over a platform. Then the high-power laser sweeps across the first powder layer, touching the required points defined in the STL file. The laser melts the steel powder, causing the steel particles to stick together. The platform moves down a bit and the process is repeated. The fabrication process is done in an enclosed chamber filled with nitrogen gas (or in a vacuum chamber) because the hot powder is highly vulnerable to oxidation. No temporary support is required because the unused powder acts as built-in support and prevents the product from collapsing.

- **3 Dimensional Printing:** 3DP currently refers to both the whole AM process and one of its techniques. The 3DP technique, which was developed by MIT researchers, is a powder-bed approach, similar to PBF, but 3DP does not use a heating-based sintering system. Instead, a high-power laser beam touches a thin layer of powder material, and the print head (nozzle) squeezes adhesive to bind the powder particles together. Almost all materials that can be supplied in powder can be used in this method. One of the advantages of a 3DP system is its simplicity in that it does not utilize highly complicated technologies such as lasers. However, it cannot make high-resolution products as can laser-based systems.
- **Beam Deposition:** The beam deposition (BD) process is referred to as laser engineered net shaping (LENS), laser metal deposition or laser-based metal deposition, laser freeform fabrication, construction laser additive direct, directed light fabrication, and directed metal deposition. Beam deposition is predominantly used for metal powders. It is similar to the SLS technique in that it uses laser as a focused heat source to melt and bind powder materials. The laser melts materials as they are blown into a laser beam. Other focused heat sources, such as an electron beam, can also be used in this technique instead of a laser. An advantage of this technique is that the substrate can be either a flat plate or an existing part onto which additional material will be added.
- **Polyjet Printing:** Polyjet printing is one the newest AM techniques. It can be considered to be a combination of LENS and SL techniques. A polyjet printing system utilizes a deposition head like LENS, using a photopolymer and UV light instead of metal powder and a laser. The photopolymer liquid is sprayed through the nozzles into a narrow beam of UV light, and solidified polymer particles are deposited on the surface and form a new layer of solid material. Polyjet printing systems can fabricate high-resolution objects.
- **Laminated Object Manufacturing (LOM):** LOM or sheet lamination involves layer-by-layer lamination of very thin sheets of material. Each sheet represents one cross-sectional layer in the CAD model. In LOM, each layer is cut—using laser or mechanical tools—from a larger sheet of material. The unused part of each sheet is cut into small cubes using a cross-hatch cutting operation. Several sheets (laminas) are cut and bound together to form the final object. Laminas are bound using gluing or adhesive bonding.

- **Extrusion-Based Systems:** Extrusion, also called fused deposition modeling (FDM), is a simple form of AM. It is quite similar to putting icing on a cake. A creamy (semisolid) substance is gradually extruded through a nozzle by applying pressure. The extruded material forms a track of the material. Integration of these tracks forms one layer of the final product. Extrusion-based systems are limited to materials with semisolid forms, which can be solidified after extrusion. Concrete works well. Thermoplastic polymers are also excellent materials for this approach. They are easily liquefied by heat and solidify instantly when they become cold.

3DP Market Size

3DP is often referred to as a disruptive technology, promising to have profound ramifications for businesses all along the supply chain. The technology is being increasingly used in aircraft manufacturing and healthcare, and is becoming a staple in some manufacturing processes. In the consumer market, Amazon offers customized toys and jewelry, Staples is testing printers out in two markets and UPS plans to put 3D printers in more than 100 stores.

Fueled by rapid technological developments, new applications and falling costs, the 3-D printer manufacturing industry has surged over the past five years. According to market research firm Wohlers Associates, the market for 3D printing, consisting of all products and services worldwide, grew to $3.07 billion in 2013. The compound annual growth rate (CAGR) of 34.9% is the highest in 17 years. The growth of worldwide revenues over the past 26 years has averaged 27%. The CAGR for the past three years (2011–2013) was 32.3% (Wohlers, 2014). Figure 10 shows revenues (in millions of dollars) for AM products and services worldwide.

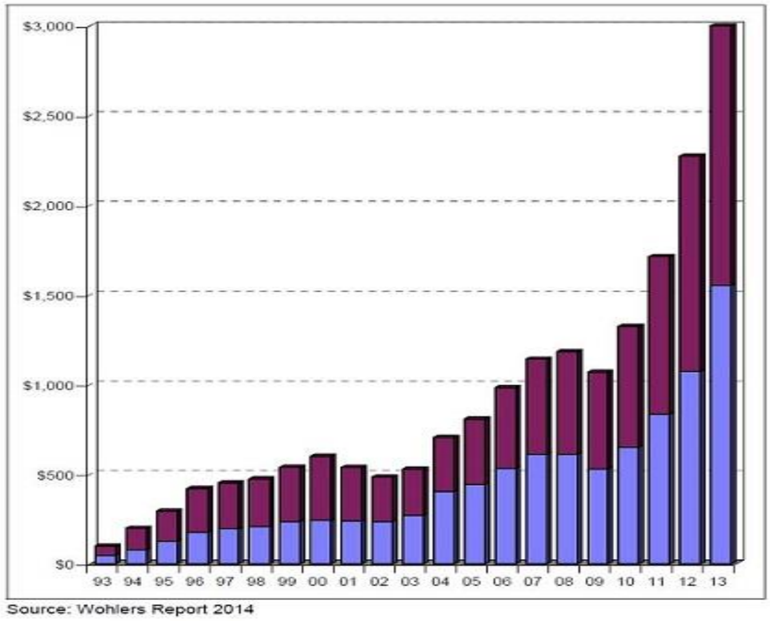

Figure 10. AM Products and Services Revenues
(Caffrey & Wohlers, 2014, p. 61)

According to a 2013 McKinsey Global Institute (MGI) report, 3D printing could generate an economic impact of $230 billion to $550 billion per year by 2025 for certain applications, from consumer uses to manufacturing. The report noted a 90% drop in home 3D printer prices in just four years and said additive manufacturing revenue increased four-fold in the past 10 years, citing revenue growth to $200–$600 billion by 2025.

Goldman Sachs described 3D printing in 2013 as a creative destroyer, having the potential to offer high degrees of customization, reduced costs for complex designs, and lower overhead costs for short-run parts and products. Goldman notes that currently the 3D printing industry is a $2.2 billion market, and its revenues will reach $10.8 billion by 2021.

A 2013 report issued by Credit Suisse investigated market opportunities in key verticals (i.e.aerospace, automotive, health care, and consumer) and concluded that those four markets alone (comprising ~50% of current 3DP market) represented opportunities to sustain 20-30% annual revenue growth (Wile, 2013). Credit Suisse projected the market to reach nearly $12 billion by the year 2020 (Figure 11).

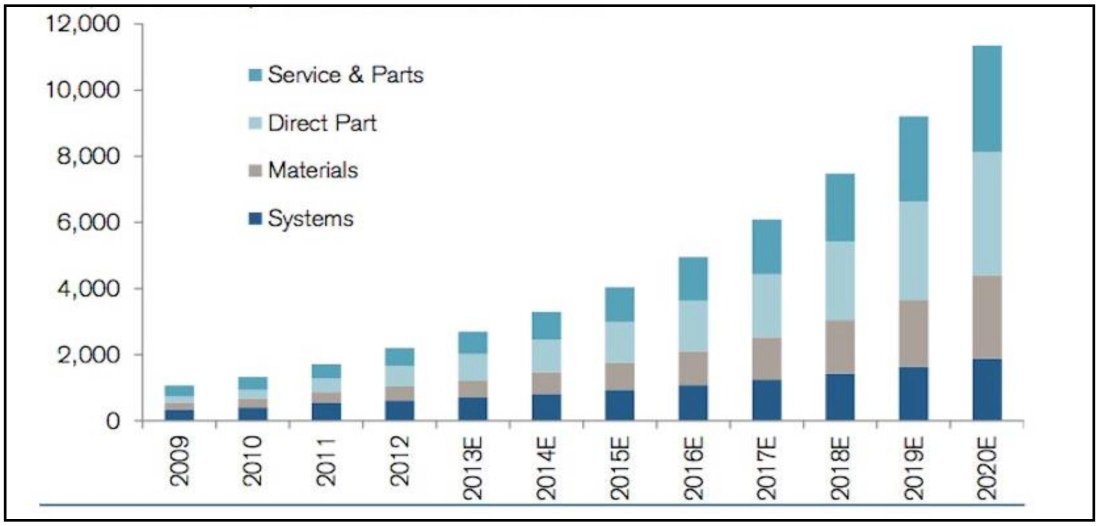

Figure 11. Primary Global AM Market (US $ Millions)
(Wile, 2013)

Credit Suisse revised the firm's 2016 projection for the market up 357%, to $800 million from $175 million, in early 2014. The company initially overlooked the opportunities among consumers and "pro-sumers," defined as engineers, architects and educators.

While there are disparities in market projections, what is clear is this much-hyped technology promises to have profound ramifications for businesses and consumers. As seen in Figure 12, Gartner's first Hype Cycle for 3D shows business and medical applications will have the biggest impact in the next two to five years while the consumer market will take a longer time.

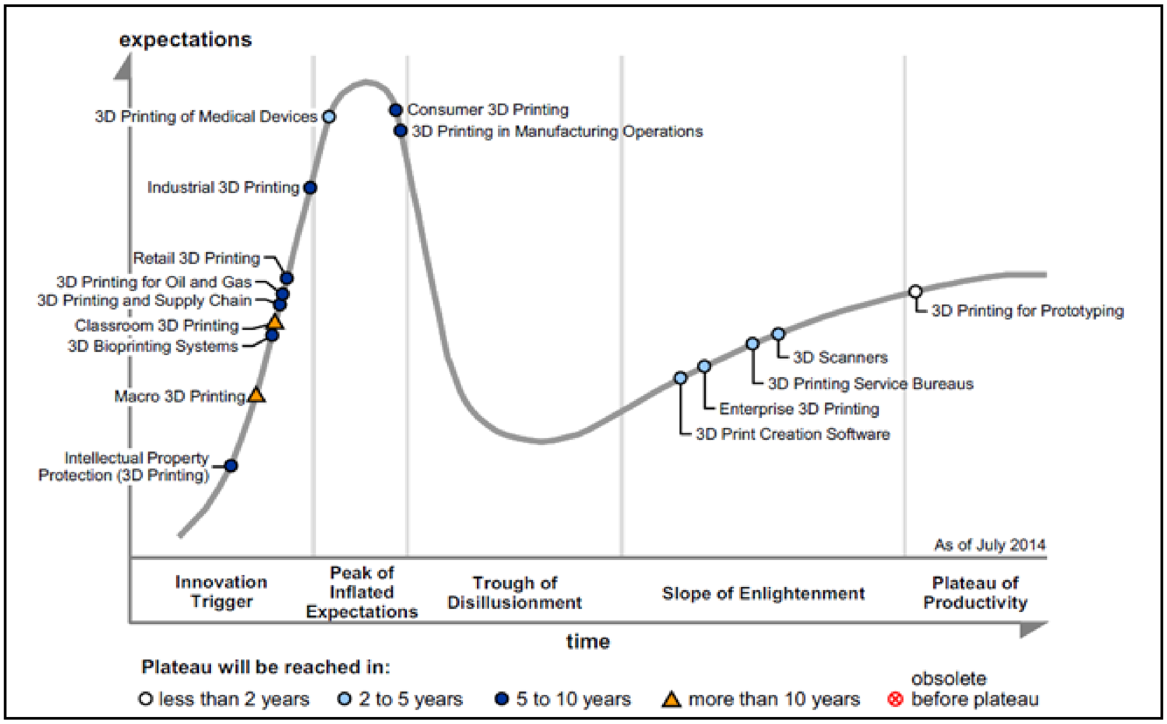

Figure 12. Gartner 3D Technology Hype Cycle
(Gartner, 2014)

Evolution of 3D Technology

In the early 1980s, Charles Hull invented stereolithography (SLA), a printing process that enables a tangible 3D object to be created from digital data. The technology is used to create a 3D model from a picture and allows users to test a design before investing in a larger manufacturing program. Hull later co-founded 3D Systems, Inc., the first company to commercialize AM technology with SLA in 1986. Since then, AM has evolved to include at least 13 different sub-technologies grouped into seven distinct process types. Figure 13 shows the evolution of additive manufacturing technology.

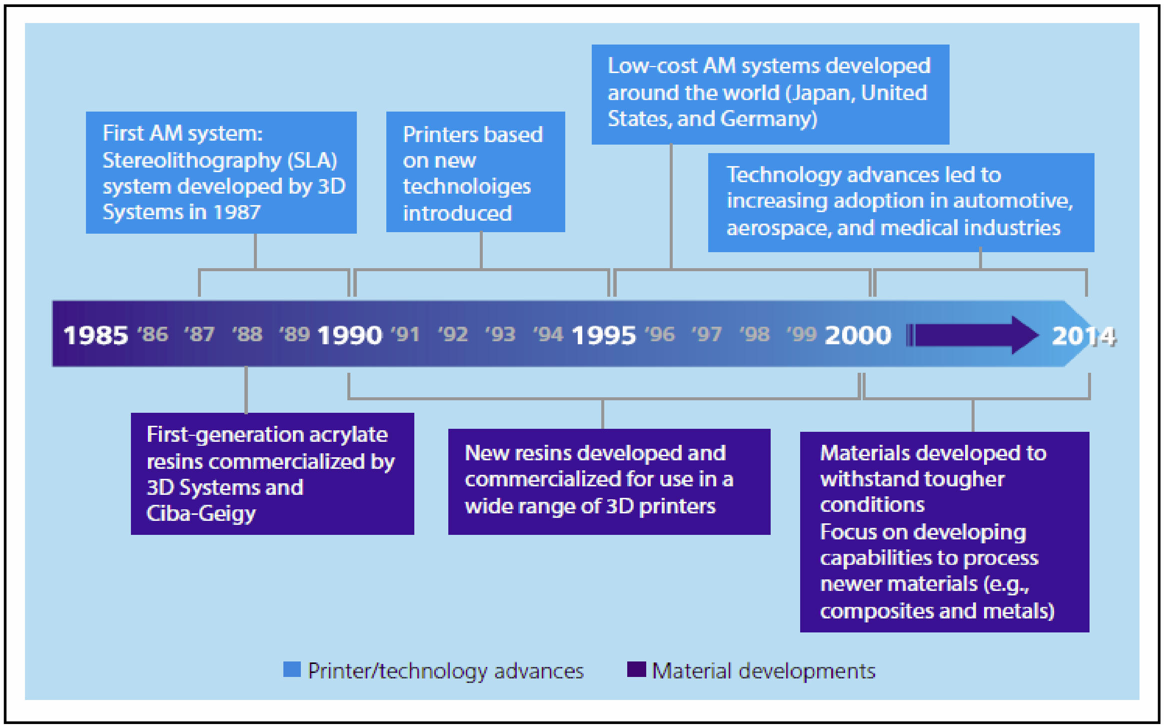

Figure 13. Evolution of AM Technology 1985–2014
(Cotteleer et al, 2013)

AM technologies use a variety of materials, including plastics, metals, ceramics, and composites, and deploy multiple different processes to address a variety of issues (i.e., unit cost, speed of operations, design complexity). AM technologies are typically based on one of the seven primary manufacturing processes published by ASTM in the “Standard Terminology for Additive Manufacturing Technologies.” In that publication, the following processes for grouping current and future AM machine technologies are identified:

- *Binder jetting*: A liquid bonding agent is selectively deposited to join powder materials.
- *Directed energy deposition*: Focused thermal energy is used to fuse materials by melting them as they are being deposited.
- *Material extrusion:* Material is selectively dispensed through a nozzle or orifice.
- *Material jetting:* Droplets of build material are selectively deposited.
- *Powder bed fusion:* Thermal energy selectively fuses regions of a powder bed.
- *Sheet lamination:* Sheets of material are bonded to form an object.

- *Vat photopolymerization*: Liquid photopolymer in a vat is selectively cured by light-activated polymerization.

Figure 14 shows four major uses and potential adoption timeframe. The first wave is rapid prototyping, followed by the second wave of molds and tooling.

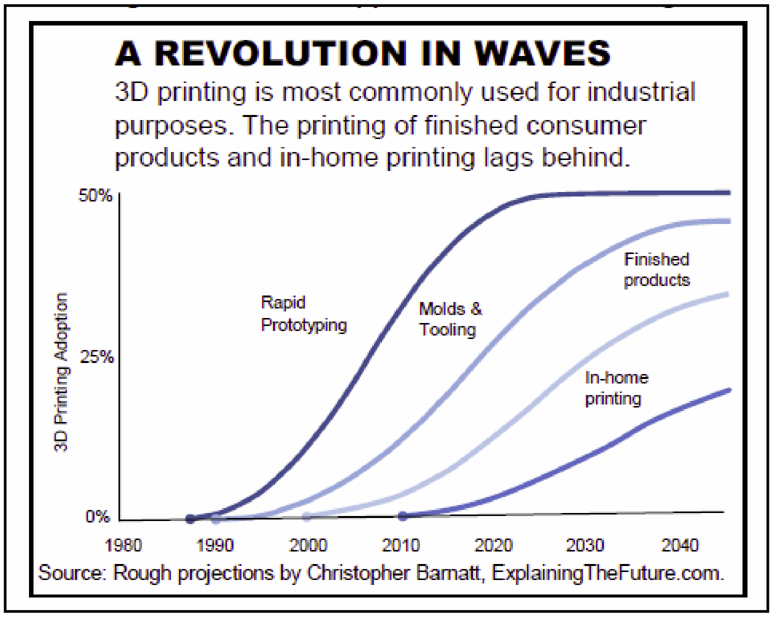

Figure 14. Application Areas for 3D Printing
(U.S. Postal Service Office of Inspector General, 2014)

Commercial Applications of Additive Manufacturing

AM is expected to grow from producing prototypes to a number of applications across many industries, as seen in Figure 15. Some companies have developed AM systems for the aerospace industry, which usually does not require high-volume production. These systems are capable of fabricating aircraft engine parts as well as interior parts of airplanes. Similar to the aerospace industry, AM systems are capable of producing functional parts for automobiles, especially race cars. Engines of racing autos have usually specific designs and include special parts that are not produced in mass quantities.

One of the major applications of AM is production of medical prostheses and implants. AM is very suitable for this purpose because artificial parts implanted in a human's body must be unique to the patient's body and damage, such as replacing a portion of a damaged skull. The implant geometry can be captured using advanced medical imaging procedures such as a CT scan, and can be produced with high accuracy and resolution using the AM process. Another advantage of using AM for this kind of bone replacement is that AM makes it possible to produce a porous implant so that bone cells can grow through it and fix the damage naturally over time. Production of dental crowns and partials also benefit from AM. Similar to medical implants, the required geometry can be captured using advanced imaging technologies, so that the artificial part would be produced as exactly as it is needed.

INDUSTRIES	CURRENT APPLICATIONS	POTENTIAL FUTURE APPLICATIONS
COMMERCIAL AEROSPACE AND DEFENSE[17]	• Concept modeling and prototyping • Structural and non-structural production parts • Low-volume replacement parts	• Embedding additively manufactured electronics directly on parts • Complex engine parts • Aircraft wing components • Other structural aircraft components
SPACE	• Specialized parts for space exploration • Structures using light-weight, high-strength materials	• On-demand parts/spares in space • Large structures directly created in space, thus circumventing launch vehicle size limitations
AUTOMOTIVE[18]	• Rapid prototyping and manufacturing of end-use auto parts • Parts and assemblies for antique cars and racecars • Quick production of parts or entire	• Sophisticated auto components • Auto components designed through crowdsourcing
HEALTH CARE[19]	• Prostheses and implants • Medical instruments and models • Hearing aids and dental implants	• Developing organs for transplants • Large-scale pharmaceutical production • Developing human tissues for regenerative therapies
CONSUMER PRODUCTS/RETAIL	• Rapid prototyping • Creating and testing design iterations • Customized jewelry and watches • Limited product customization	• Co-designing and creating with customers • Customized living spaces • Growing mass customization of consumer products

Figure 15. Potential Applications of 3D
(Cotteleer et al., 2013)

Aerospace companies such as Boeing, Airbus, Lockheed Martin, Pratt & Whitney, Rolls-Royce, Honeywell, and MTU Aero Engines are accelerating involvement and investments in AM. According to Wohlers Associates, Boeing has installed environmental control system ducting made by AM for its commercial and military aircraft for many years. Tens of thousands of AM parts are flying on 16 different production aircraft (both commercially and military). Lockheed Martin estimates that some complex satellite components can be produced 48% cheaper and 43% faster with 3D. Moreover, production costs could be reduced by as much as 80%. Aerospace applications and demonstrations of 3D include

- NASA's Juno satellite has 3D printed parts that are lighter and less costly, manufactured by Lockheed Martin in its final assembly. Lockheed is preparing to use 3D printing processes to manufacture production parts for other aircraft and spacecraft.
- Engineers at NASA's Marshall Space Flight Center in Huntsville, AL, have also been testing 3D-printed components for rocket engines. Printing a rocket-engine injector piece reduced the cost of the $300,000 part by 80%, according to a report by *Nature* magazine.
- Boeing has installed environmental control system ducting made by AM for its commercial and military aircraft for many years. Tens of thousands of AM parts are flying on 16 different production aircraft—both commercial and military. (Wohlers, 2014)
- GE Aviation announced in 2013 that it would be using AM to print metal parts for jet engines. AM will be used to manufacture more than 30,000 fuel nozzles annually for its new LEAP engine starting in 2015. Consolidating 18 parts into one, the new design is 25% lighter and five times more durable than the previous fuel nozzle.
- Airbus has 20 AM projects underway, with a few hundred part numbers currently flying or soon will be, on the new A350 airplane. A structural cabin bracket made by AM in the titanium alloy Ti-6Al-4V will fly on an A350 mid year.
- Airbus is also using 3D printing to produce a seat belt mold as a spare part for the A310 jet. According to the head of research and technology for industrial systems in the Manufacturing Engineering Centre of Competence at Airbus, the company plans to use 3D printed plastic parts for the A350 aircraft by early 2015. Even with small components, a 50% weight savings and a cost savings of 60 to 70% on production parts is anticipated. (Mitchell, 2014).

GE Aviation is investing heavily into AM and other advanced technologies. For example, it will open a new $100 million assembly plant that will employ 200 people by 2020, to build the world's first passenger jet engine with 3D printed fuel nozzles and next-generation materials. Although the engine, called LEAP, will not enter service until 2016 on the Airbus A320, it has already become GE Aviation's bestselling engine, with more than 6,000 confirmed orders from 20 countries, valued at over $78 billion (GE, 2014). Each LEAP engine has 19 3D-printed fuel nozzles inside, fourth-generation carbon-fiber composite blades, and parts made from CMCs. In addition to the 3D-printed nozzles being five times more durable than the previous model, 3D printing allowed engineers to use a simpler design that reduced the number of brazes and welds from 25 to just five. There are currently more than 300 3D printing machines currently in use across GE. Moreover, GE Aviation predicts that 100,000 additive parts will be manufactured by 2020.

The consultancy firm PwC estimates that the benefits of potential 3D adoption in the aerospace MRO market found that global aerospace MRO costs could be reduced by up to $3.4 billion, assuming that 50% of parts are printed (PwC, 2014). Even if 15% of aerospace replacement parts could be printed, there could be over $1 billion of materials and transportation-related savings.

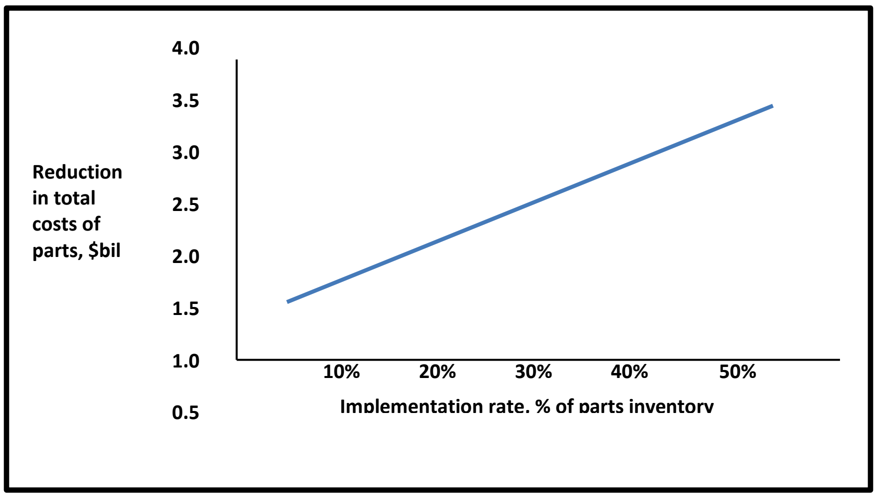

Figure 16. Potential $3.4 Billion in MRO Savings With 3DP in Global Aerospace Industry
(PWC, 2014, p. 12)

The automotive sector is also accelerating its use of AM. Ford Motor uses 3D printing in several areas, including the tooling used to create production parts and to build intake manifold prototypes that can be tested for up to 100,000-mile cycles. By traditional manufacturing methods, it would cost $500,000 and four months to build while a 3D-printed manifold prototype costs $3,000 to build over four days. Ford also uses 3D to build “bridging parts” that can be included in nonproduction vehicle assembly until conventionally manufactured parts are available, and as a way to manufacture parts made out of more than one material in a single step. For example, a handle that includes both hard plastic and soft rubber components would usually require a two-step process when using conventional manufacturing techniques. In the future, Ford is looking at using 3D printing to produce some replacement parts on demand (Mitchell, 2014). Table 7 summarizes some of the savings achieved in business.

Table 7. 3D Efficiency and Cost Savings

COMPANY	ITEM	TRADITIONAL MANUFACTURING	ADDITIVE MANUFACTURING
Ford Motor Co.	Manifold Prototype	Cost - $500,000 Time - 4 months	• Cost - $3,000 • Time – 4 days
Airbus	Parts	X (information not available	• Weight savings - 50% • Cost savings - 60 to 70%
GE Aviation	Fuel Nozzle	X (information not available	• Consolidates 18 parts into 1 • 25% lighter • 5 X more durable
Lockheed Martin	X (information not available	X (information not available	• 43% Cycle time reduction • 48% Cost reduction

The United States has been the global leader in AM since its beginning, having launched many of the most successful companies in the field, including 3D Systems, Stratasys, Z Corporation, and Solidscape. In an analysis conducted by the Science & Technology Institute (IDA), IDA found that the U.S. government has played a role in the early development of AM by

- *Department of Defense*: Office of Naval Research (ONR) and the Defense Advanced Research Projects Agency (DARPA) were some of the earliest investors in AM by providing steady streams of funding for both academic and industry-based researchers.
- *National Science Foundation:* NSF funded precursors of AM technologies in the 1970s (development of computer numerical controlled machining and solid modeling tools) and turned early AM patents in the 1980s into proof-of-concept and prototype machines in two major commercial technology areas (binder jetting and laser sintering). NSF also later funded application development (e.g., medical) and academically oriented networking activities. It has supported research efforts related to new processes, new applications for existing processes, and benchmarking and roadmapping activities as AM technologies matured. NSF has awarded almost 600 grants for AM research and other activities, amounting to more than $200 million (2005 dollars) in funding.
- *Other support*: The Department of Energy (DOE), NASA, and the National Institute of Standards and Technology (NIST) have also been involved in aspects of developing the AM field. DOE in particular

played a role in developing directed energy deposition technologies. (IDA, 2013)

The U.S. Navy has supported research into 3D printing for more than 20 years and has approximately 70 additive manufacturing projects underway at dozens of different locations. The Chief of Naval Operations is in the process of developing the Navy's additive manufacturing vision and strategy. The following projects demonstrate how AM is transforming Navy logistics and maintenance capabilities through reduced costs, efficiency gains and parts replacement.

- Norfolk Naval Shipyard's Rapid Prototype Lab is saving thousands of dollars on the Gerald R. Ford-class of aircraft carriers. The lab prints much cheaper plastic polymer models in hours versus days or weeks, rather than the traditional wood or metal mockups of ship alterations. All four Navy shipyards have 3D printers working on similar and other ways to benefit the Navy.
- Navy's Fleet Readiness Center Southeast uses AD for more complicated designs and unique material properties to develop an enhanced hydraulic intake manifold for the V-22 Osprey. This manifold has fewer leak points than its traditionally manufactured counterpart, is 70% lighter, and improves fluid flow.
- Walter Reed National Military Medical Center (WRNNMC) uses AM to meet a range of medical needs and delivers personalized patient care. With easily customizable 3D printed parts, WRNNMC produces items including tailor-made cranial plate implants, medical tooling, and surgical guides.
- Naval Undersea Warfare Center-Keyport used additive manufacturing to create a supply of replacement parts to keep the Fleet ready. The circuit card clip for J-6000 Tactical Support System Servers, installed onboard Los Angeles-class nuclear-powered guided-missile submarines, and Ohio-class nuclear-powered guided-missile submarines is no longer produced by its original manufacturer (Collom, 2014).
- CNO's Rapid Innovation Cell Print the Fleet project installed a 3D printer aboard USS *Essex* this year, demonstrating the ability to develop and print a variety of shipboard items, from oil reservoir caps and deck drain covers to training aids and tools.
- USS *Essex* crew has printed everything from plastic syringes to oil tank caps, to the silhouettes of planes that are used on the mock-up of the flight deck to keep the flight deck organized.

Summary

Additive manufacturing is a relatively new technology that directly deposits materials to make products by sequentially laying down millions of particles in thousands of layers to “build up” the final component. 3 dimensional design documents direct manufacturing hardware. By controlling the movement of the material deposition equipment and the flow of material, the process controls where particles are deposited in each layer, thereby creating surfaces, shapes, and cavities. Materials can be plastic for fast prototyping, metals, ceramics, or human tissue. 3D printing has several advantages over traditional manufacturing methods. First, a primary advantage is the ability to create almost any shaped product, with the only limitation being the need for each layer of material to have a layer below it for support, although secondary materials can be used to provide support under overhanging component parts during manufacturing. Second, whereas traditional methods are subtractive, the AM process is additive, greatly reducing waste materials.

Collaborative Product Lifecycle Management

Product lifecycle management address the issues related to a product throughout its life. Collaborative product lifecycle management (CPLM) works to integrate product lifecycle management across project participants, time, and technologies. CPLM technology provides a common platform to electronically integrate other technologies, such as 3DLST images and manufacturing files for Additive Manufacturing , to enable collaboration among all parties involved in a given project across project phases and regardless of their geographic location (e.g., on a ship at sea and at a land-based depot). Schindler (2010; see Figure 17) illustrated the potential of CPLM to facilitate integration of the development of material solutions.

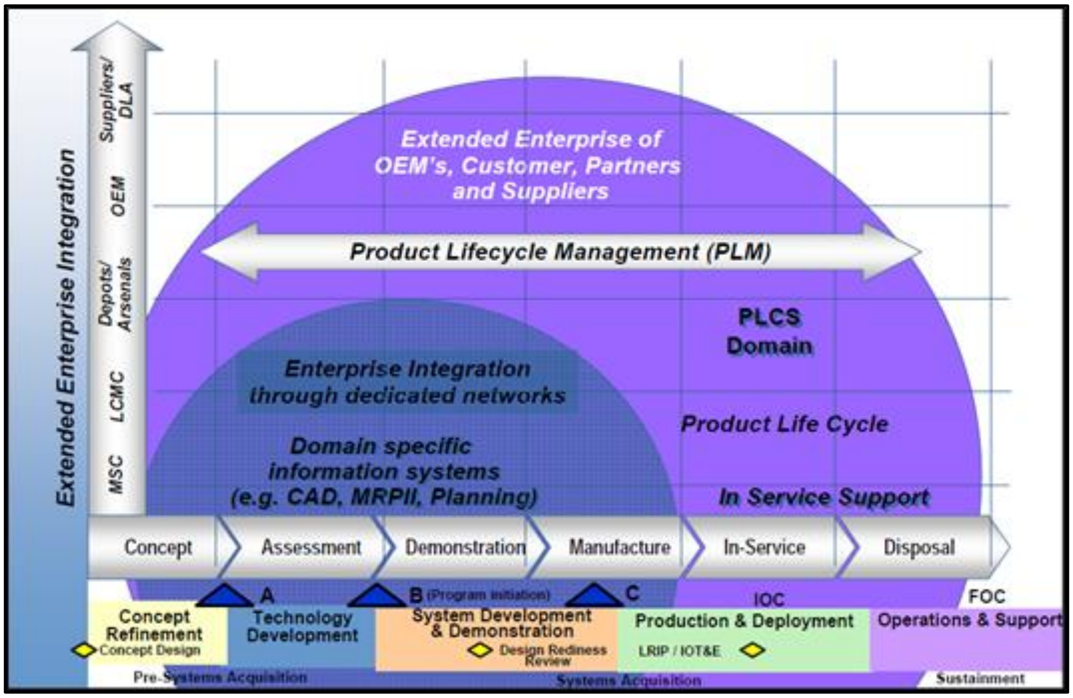

Figure 17. Collaborative Product Lifecycle Management Across the Life Cycle
(Schindler, 2010).

CPLM tools also provide a means to store the images and all related maintenance work within a common database accessible by all participants in a ship alteration or modernization project. PLM is defined by CIMdata as a strategic business approach applying a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise, from concept to end of life (CIMdata, 2007).[2] It integrates people, processes, and information.

Specific CPLM tools include technologies that support data exchange, portfolio management, digital manufacturing, enterprise application integration, and workflow automation. A range of industries has invested in CPLM solutions, including those involved in aerospace and defense, automotive and transportation, utilities, process manufacturing, and high-tech development and manufacturing. The CPLM market is poised for further growth with vendors expanding product offerings as the industry evolves.[3] Figure 18 indicates the evolution of CPLM applications,

[2] CIMdata is a consulting firm with over 20 years of experience in strategic IT applications and is an acknowledged leader in the application of PLM and related technologies.
[3] The two largest U.S. shipyards that construct aircraft carriers and submarines are also transitioning into CPLM solutions. Typically, PLM vendors do not focus efforts on the shipbuilding industry because of its size relative to other products, such as automotive or aerospace. Having a PLM tool designed specifically for an industry has a significant impact on the tools efficiency within that industry.

illustrating their stages before reaching the “plateau of productivity” in the mainstream market.

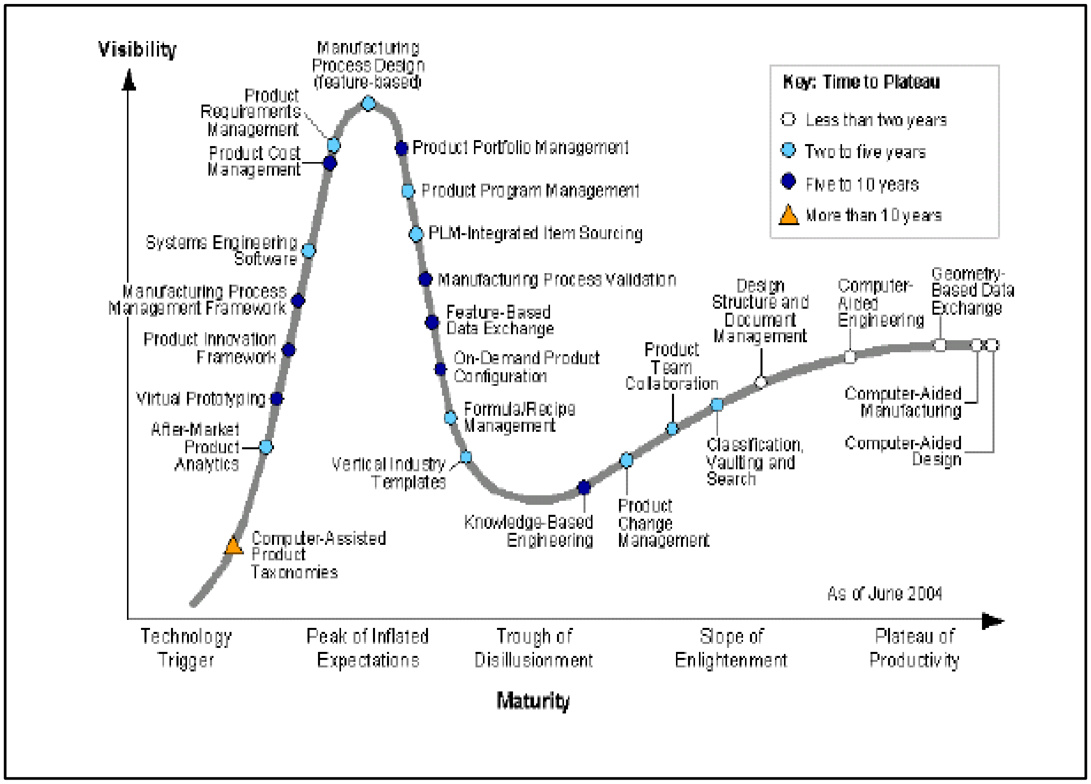

Figure 18. Evolution of CPLM
(Halpern & Smith, 2004)

3 Dimensional Laser Scanning Technology

3 dimensional (3D) scanners create a “point cloud“ of the surface of an object. Similar to cameras in some ways, they have a cone-shaped field of view, but can also collect distance information about each point, allowing each point to be located in a 3 dimensional space. Usually, multiple scans are required from different directions to capture adequate information to create a description of the object. Most manufacturers’ scanners work by scanning a target space with a laser light mounted on a highly articulating mount, enabling data capture in virtually any orientation with minimal operator input. Some also incorporate a digital camera that simultaneously captures a 360° field-of-view color photo image of the target. Once the capture phase is complete, the system automatically executes proprietary point-processing algorithms to process the captured image. The system can generate an accurate[4] digital 3D model of the target space, automatically fuse image texture onto 3D model

[4] The National Shipbuilding Research Program’s (NSRP) studies (2006 & 2007b) requirement was within 3/16 of an inch to actual measurements.

geometry, export file formats ready for commercial, high-end design, and import them into 2D/3D computer-aided design (CAD) packages.

Terrestrial laser scanning technology is well established as a valuable tool in practice and is currently used in a variety of industries. According to industry analysts, laser scanner manufacturers and related software and service providers report strong activity across many markets, including shipbuilding, offshore construction and repair, onshore oil and gas, fossil and nuclear power, civil and transportation infrastructure, building, automotive and construction equipment, manufacturing, and forensics (Greaves & Jenkins, 2007). In the latest data available, sales of terrestrial 3D laser scanning hardware, software, and services reached $253 million in 2006—a growth of 43% over 2005 (Greaves & Jenkins, 2007).

Research Approaches and Methods

This research developed estimates of the impacts of the three technologies (3DLST, 3DP, and CPLM) on fleet maintenance costs by comparing the costs of different make/buy strategies. The background, issues, and cost estimates were then used in the real options approach.

To estimate the make/buy strategy costs, the traditional investment analysis approach was reverse-engineered using the following steps:

- Describe the make/buy strategies.
- Estimate revenues that reflect benefits using a market-comparable approach.
- Estimate a return on investment (ROI) for each strategy using Knowledge Value Added models.
- Estimate costs of each make/buy strategy using the ROI estimates and estimates of benefits.
- Estimate potential cost savings by comparing costs of make/buy strategies.

The Knowledge Value Added (KVA) modeling methodology is central to estimating the make/buy strategy costs. KVA measures the value provided by human capital and IT assets by an organization, process, or function at the subprocess level (see Figure 19). It monetizes the outputs of all assets, including intangible knowledge assets. Capturing the value embedded in an organization’s core processes, employees, and IT enables calculation of the actual cost and revenue of a product or service (see Figure 20).

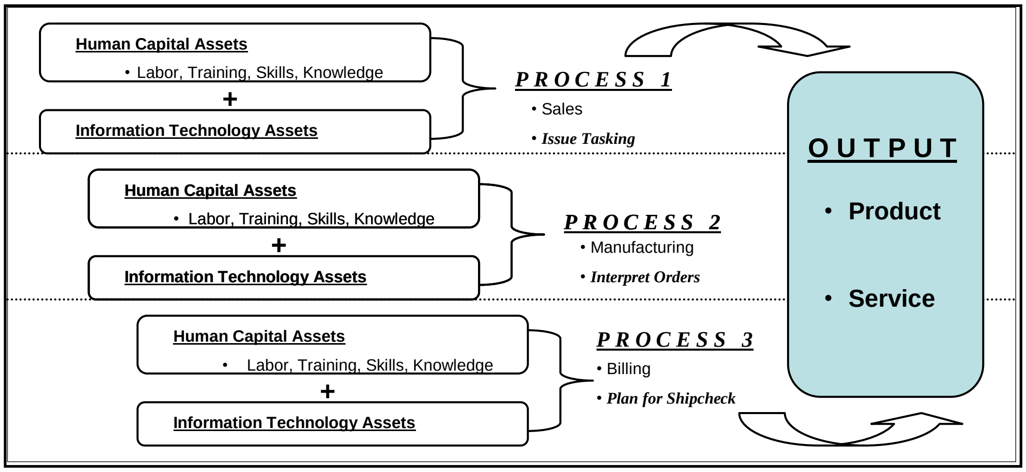

Figure 19. Measuring Output

Explains what was spent

Traditional Accounting		KVA Process Costing	
Compensation	$5,000	Review Task	$1,000
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
Total	**$11,400**	Format Report	600
		Quality Control Report	700
		Transmit Report	1,600
		Total	**$11,400**

Explains how it was spent

Figure 20. Comparison of Traditional Accounting Versus Process-Based Costing

Total value is captured in two key metrics: return on investment (ROI) and return on knowledge (ROK; see Table 8). Although ROI is the traditional financial ratio, ROK identifies how a specific process converts existing knowledge into producing outputs so decision makers can quantify costs and measure value derived from investments in human capital assets. A higher ROK signifies better utilization of knowledge assets. If technology investments do not improve the ROK value of a given process, steps must be taken to improve that process's function and performance.

Table 8. Knowledge Value Added 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 Output
Return on Investment (ROI)	Same as ROI at the subcorporate, process level	Traditional investment finance ratio	(Revenue-Investment Cost) / Investment cost

The goal is to determine which core processes provide the highest ROIs and ROKs, and to make suggested process improvements based on the results. In the current work, KVA is used to measure the benefits of technology adoption in ship maintenance. This analysis provides a means to check the reliability of prior studies' estimates of the potential ROI core process improvements from using CPLM, AM (3DP), and 3DLST in ship-maintenance core processes in the U.S. Navy yards.

Integrated Risk Management and Strategic Real Options Analysis

Integrated Risk Management (IRM) is an eight-step, quantitative software-based modeling approach for the objective quantification of risk (cost, schedule, technical), flexibility, strategy, and decision analysis. The method can be applied to program management, resource portfolio allocation, return on investment to the military (maximizing expected military value and objective value quantification of nonrevenue government projects), analysis of alternatives or strategic flexibility options, capability analysis, prediction modeling, and general decision analytics. The method and toolset provide the ability to consider hundreds of alternatives with budget and schedule uncertainty, and provide ways to help the decision-maker maximize capability and readiness at the lowest cost. This methodology is particularly amenable to resource reallocation and has been taught and applied by the authors for the past 10 years at over 100 multinational corporations and over 30 projects at the DOD.

IRM provides a structured approach that will yield a rapid, credible, repeatable, scalable, and defensible analysis of cost savings and total cost of ownership while ensuring that vital capabilities are not lost in the process. The IRM + KVA methods do this by estimating the value of a system or process in a common and objective way across various alternatives and providing the return on investment (ROI) of each in ways that are both comparable and rigorous. These ROI estimates across the portfolio of alternatives provide the inputs necessary to predict the value of various options. IRM incorporates risks, uncertainties, budget constraints, implementation, lifecycle costs, reallocation options, and total ownership costs in providing a defensible analysis describing management options for the path forward. This approach identifies risky projects and programs, while projecting immediate and future cost savings, total lifecycle costs, flexible alternatives, critical success factors, strategic options for optimal implementation paths/decisions, and portfolio optimization. Its employment presents ways for identifying the potential for cost overruns and schedule delays and enables proactive measures to mitigate those risks. IRM provides an optimized portfolio of capability or implementation options while maintaining the value of strategic flexibility.

In the extant case, IRM provides a way to differentiate among various alternatives for implementation of 3DLST, CPLM, PDF and Logistics Team Center with respect to ship maintenance processes, and to postulate where the greatest benefit could be achieved for the available investment from within the portfolio of alternatives. As a strategy is formed and a plan developed for its implementation, the toolset provides for inclusion of important risk factors, such as schedule and technical uncertainty, and allows for continuous updating and evaluation by the program manager to understand where these risks come into play and make informed decisions accordingly.

IRM Modeling Approach

Through the use of Monte Carlo simulation, the resulting stochastic KVA ROK model yielded a distribution of values rather than a point solution. Thus, simulation models analyze and quantify the various risks and uncertainties of each program. The result is a distribution of the ROKs and a representation of the project's volatility.

In real options, the analyst assumes that the underlying variable is the future benefit minus the cost of the project. An implied volatility can be calculated through the results of a Monte Carlo simulation. The results for the IRM analysis will be built on the quantitative estimates provided by the KVA analysis. The IRM will provide defensible quantitative risk analytics and portfolio optimization suggesting the best way to allocate limited resources to ensure the highest possible value over time.

The first step in real options is to generate a strategic map through the process of framing the problem. Based on the overall problem identification occurring during the initial qualitative management screening process, certain strategic options would become apparent for each particular project. The strategic options could include, among other things, the option to wait, expand, contract, abandon, switch, stage-gate, and choose.

Risk analysis and real options analysis assume that the future is uncertain and that decision-makers have the ability to make midcourse corrections when these uncertainties become resolved or risk distributions become known. The analysis is usually done ahead of time and, thus, ahead of such uncertainty and risks.

Therefore, when these risks become known, the analysis should be revisited to incorporate the information in decision-making or to revise any input assumptions. Sometimes, for long-horizon projects, several iterations of the real options analysis should be performed, where future iterations are updated with the latest data and assumptions. Understanding the steps required to undertake an integrated risk management (IRM) is important because the methodology provides insight not only into the methodology itself but also into how IRM evolves from traditional analyses, showing where the traditional approach ends and where the new analytics start.

The risk simulation step required in the IRM provides us with the probability distributions and confidence intervals of the KVA methodology's resulting ROI and ROK results. Further, one of the outputs from this risk simulation is volatility, a measure of risk and uncertainty, which is a required input into the real options valuation computations. In order to assign input probabilistic parameters and distributions into the simulation models, we relied on the U.S. Air Force's Cost Analysis Agency (AFCAA) handbook as seen in Figure 21. In the handbook, the three main distributions recommended are the triangular, normal, and uniform distributions. We chose the triangular distribution because the limits (minimum and maximum) are known, and the shape of the triangular resembles the normal distribution, with the most likely values having the highest probability of occurrence and the extreme ends (minimum and maximum values) having considerably lower probabilities of occurrence. Also, the triangular distribution was chosen instead of the normal distribution because the latter's tail ends extend toward positive and negative infinities, making it less applicable in the model we are developing. Finally, the AFCAA also provides options for left skew, right skew, and symmetrical distributions. In our analysis, we do not have sufficient historical or comparable data to make the proper assessment of skew and, hence, revert to the default of a symmetrical triangular distribution.

AFCAA Cost Risk Analysis Handbook

Table 2-5 Default Bounds for Subjective Distributions

Distribution	Point Estimate Interpretation	Point Estimate and Probability	Mean	15%	85%
Triangle Low Left	Mode	1.0 (75%)	0.878	0.695	1.041
Triangle Low	Mode	1.0 (50%)	1.000	0.834	1.166
Triangle Low Right	Mode	1.0 (25%)	1.122	0.959	1.305
Triangle Med Left	Mode	1.0 (75%)	0.796	0.492	1.069
Triangle Med	Mode	1.0 (50%)	1.000	0.723	1.277
Triangle Med Right	Mode	1.0 (25%)	1.204	0.931	1.508
Triangle High Left*	Mode	1.0 (75%)	0.745	0.347	1.103
Triangle High	Mode	1.0 (50%)	1.000	0.612	1.388
Triangle High Right	Mode	1.0 (25%)	1.286	0.903	1.711
Triangle EHigh Left**	Mode	1.0 (75%)	0.745	0.300	1.150
Triangle EHigh	Mode	1.0 (50%)	1.004	0.509	1.500
Triangle EHigh Right	Mode	1.0 (25%)	1.367	0.876	1.914

Figure 21. U.S. Air Force Cost Analysis Agency (US. AFCAA) Handbook's Probability Risk Distribution Spreads

Strategic Real Options

As described previously, an important step in performing IRM is the application of Monte Carlo risk simulation. By applying Monte Carlo risk simulation to simultaneously change all critical inputs in a correlated manner within a model, researchers can identify, quantify, and analyze risk. The question then is, what next? Simply quantifying risk is useless unless it can be managed, reduced, controlled, hedged, or mitigated. This is where strategic real options analysis comes in. Think of real options as a strategic road map for making decisions.

The real options approach incorporates a learning model, such that the decision-maker makes better and more informed strategic decisions when some levels of uncertainty are resolved through the passage of time, actions, and events. The combination of the KVA methodology (to monitor the performance of given options) and the adjustments to real options as leaders learn more from the execution of given options provides an integrated methodology to help military leaders hedge their bets while taking advantage of new opportunities over time. Traditional analysis assumes a static investment decision, and assumes that strategic decisions are made initially with no recourse to choose other pathways or options in the future. Real options analysis can be used to frame strategies to mitigate risk, to value and find the optimal strategy pathway to pursue, and to generate options to enhance the value of the project while managing risks. Imagine real options as a guide for navigating through unfamiliar territory, providing road signs at every turn to direct drivers in making the best and most informed driving decisions. This is the essence of real options. From the options that are framed, Monte Carlo simulation and stochastic forecasting, coupled with traditional techniques, are applied. Then, real options analytics are applied to solve and value each strategic pathway and an informed decision can be made.

Cost Saving Estimates

Several challenges arise in expanding previous research on Navy investment strategies in new technologies to investigate make/buy strategies. One challenge is that previous research was often based on a specific portion of the parts used in Naval ship maintenance (e.g., high-, medium-, or low-complexity parts). These product types differ in their costs and market comparable values and, therefore, in their contributions to fleet readiness. Make/buy analysis should consider the potential for in-sourcing all three types of parts. A second challenge is differentiating costs generated by industry from costs generated by parts production by the Navy. These costs differ due primarily to differences in labor costs. A third challenge is the description of the make/buy strategies.

Describing Make/buy Strategies

Estimates of annual production rates are based on data collected for one depot that manufactures approximately 27,000 parts per year, of which 25% were high complexity, 50% were medium complexity, and 25% were low complexity (Mackley, 2014). Table 9 shows the estimated industry and Navy production rates for five make/buy strategies ranging from all-buy (100% by industry) to all-make (100% by Navy). These estimates assume that the Navy would produce highly complex parts first (in the lowest "make" strategy), then add medium-complexity parts as it increased the fraction of parts made, and produce low-complexity parts only in strategies that have the Navy making all the parts (in the highest "make" strategy).

Table 9. Annual Production Rate Estimates of Five Make/buy Strategies

Part Complexity (% of total parts)		High (25%)		Medium (50%)		Low (25%)		Parts Produced by Industry	Parts Produced by Navy	Total Parts Produced
	Part Manufacturer	Industry	Navy	Industry	Navy	Industry	Navy			
% Made by Navy	0	6,750	0	13,500	0	6,750	0	27,000	0	27,000
	25	0	6,750	13,500	0	6,750	0	20,250	6,750	27,000
	50	0	6,750	6,750	6,750	6,750	0	13,500	13,500	27,000
	75	0	6,750	0	13,500	6,750	0	6,750	20,250	27,000
	100	0	6,750	0	13,500	0	6,750	0	27,000	27,000

The production rates reflect two extreme strategies and three shared-production strategies. The first strategy (0% Navy production) is the extreme strategy in which all parts are made by industry. This strategy is relatively close to the current conditions in which most parts production is outsourced to industry. The second strategy (25% Navy production) reflects the Navy producing all complex parts and outsourcing all medium-complexity and low-complexity (aka “simple”) parts to industry. The third strategy (50% Navy production) reflects the Navy producing all high-complexity parts and half of the medium-complexity parts, while outsourcing half of the medium complexity parts and all simple parts to industry. The fourth strategy (75% Navy production) reflects the Navy producing all high- and medium-complexity parts and outsourcing all simple parts. The last strategy (100% Navy production) is the extreme strategy in which all parts are made by the Navy.

As shown in the “Total Parts Produced by Industry” and “Total Parts Produced by Navy” columns, the Navy increases production as the make/buy strategies shift from low percentage made by the Navy to higher percentages made. The “Total Parts Produced” column shows that these strategies reflect shifts in production between industry and the Navy, not changes in the total number of parts produced.

Estimating Revenues that Reflect Benefits

Benefits were estimated by multiplying the production rates in Table 9 by the average part values. The conservative $6,000 average value of a complex part is supported by an interview of an expert by one of the research team (Housel). That expert said, “Externally we see charges anywhere between $6,000 to $8,000 dollars and upwards of $15,000 per model” and later confirmed that $12,000 was “at the upper end of your range” (personal interview summarized in Kenney, 2013). The modelers assumed that medium-complexity parts had an average value of $3,000 each and that low-complexity parts had an average value of $1,000 each. Table 10 shows the estimated values of produced parts for each make/buy strategy.

Table 10. Estimated Annual Benefits of Five Make/Buy Strategies

	Complexity (% of total	High (25%)		Medium (50%)		Low (25%)		Parts Value Produced by Industry ($1,000/yr)	Parts Value Produced by Navy ($1,000/yr)	Total Parts Value ($1,000/yr)
	Part Manufacturer	Industry	Navy	Industry	Navy	Industry	Navy			
	Avg. Part Value ($1,000/part)	6	6	3	3	1	1			
% Made by Navy	0	$40,500	$0	$40,500	$0	$6,750	$0	$87,750	$0	$87,750
	25	$0	$40,500	$40,500	$0	$6,750	$0	$47,250	$40,500	$87,750
	50	$0	$40,500	$20,250	$20,250	$6,750	$0	$27,000	$60,750	$87,750
	75	$0	$40,500	$0	$40,500	$6,750	$0	$6,750	$81,000	$87,750
	100	$0	$40,500	$0	$40,500	$0	$6,750	$0	$87,750	$87,750

Note. Benefits are estimated in thousands of dollars per year.

Estimating Returns on Investment

Estimated Returns on Investment (ROI) were generated with KVA models using the methodology describe previously. Each KVA model reflected the appropriate average 2013 labor costs (Navy) based on work by Mackley (2014) and market value of the common unit of output (high-, medium-, or low-complexity parts). The estimated Returns on Investment are shown in Table 11.

Table 11. Estimated Returns on Investment (ROI) of Five Make/buy Strategies

Part Complexity (% of total parts)		High (25%)		Medium (50%)		Low (25%)	
Part Manufacturer		Industry	Navy	Industry	Navy	Industry	Navy
% Made by Navy	0	573%	NA	151%	NA	12%	NA
	25	NA	1120%	151%	NA	12%	NA
	50	NA	1120%	236%	510%	12%	NA
	75	NA	1120%	NA	358%	12%	NA
	100	NA	1120%	NA	358%	NA	103%

The relatively large returns in Table 11 are consistent with the savings found by industry (Table 7).

Estimating Production Costs and Cost Savings

Costs for each make/buy scenario can be estimated using the definition of Return on Investment:

ROI = (Benefits – Costs) / Costs

which can alternatively be written as

Cost = Benefits / (ROI + 1).

The equation above was used with the benefits (Table 10) and Returns on Investment (Table 11) to estimate the costs of each make/buy strategy. The total cost of each make/buy scenario (rows in Table 12) is the sum of six costs: the costs generated by industry to produce high-, medium-, and low-complexity parts plus the costs generated by the Navy to produce high-, medium-, and low-complexity parts. In some strategies some of these costs are zero, such as the Navy cost when 100% of parts are produced by industry or industry cost when 100% of parts are produced by the Navy. Capturing all six cost components for each strategy assures the inclusion of all relevant production costs.

Table 12. Estimated Annual Costs of Five Make/buy Strategies

	Part Complexity (% of total parts)	High (25%)		Medium (50%)		Low (25%)		Parts Cost by Industry ($1,000/yr)	Parts Cost by Navy ($1,000/yr)	Total Parts Production Cost ($1,000/yr)
	Part Manufacturer	Industry	Navy	Industry	Navy	Industry	Navy			
% Made by Navy	0	$6,022	$0	$16,109	$0	$6,022	$0	$28,152	$0	$28,152
	25	$0	$3,319	$16,109	$0	$6,022	$0	$22,130	$3,319	$25,449
	50	$0	$3,319	$6,022	$3,319	$6,022	$0	$12,043	$6,638	$18,681
	75	$0	$3,319	$0	$8,841	$6,022	$0	$6,022	$12,160	$18,181
	100	$0	$3,319	$0	$8,841	$0	$3,319	$0	$15,479	$15,479

Figure 22 shows these results in graphical form by plotting the costs in the "Parts Cost by Industry," "Parts Cost by Navy," and "Total Parts Production Cost" columns of Table 12.

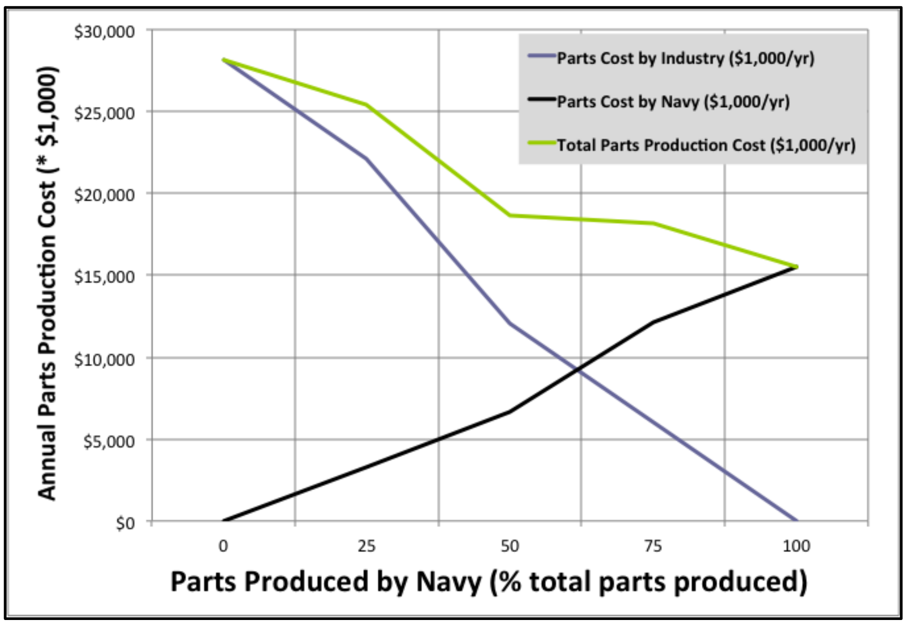

Figure 22. Estimated Annual Costs of Five Make/Buy Strategies

Savings increase with the volume of parts manufactured by the Navy (more in-sourcing). Savings at the depot studied by having the Navy instead of industry produce all parts are estimated to be $12,673,000 ($28,152k–$15,479k) per year at the depot investigated. Assuming 10 depots that apply this strategy implies savings that exceed $120 million annually. For context, these estimated savings can be compared to the threshold set by the National Defense Authorization Act for Fiscal Year 2012:

> (e) Determination relating to the conversion [from outsourcing to in-sourcing] of certain functions…in determining whether a function should be converted to performance by Department of Defense civilian employees, the Secretary of Defense shall - …

(C) Ensure that the difference in the cost of performing the function by a contractor compared to the cost of performing the function by Department of Defense civilian employees would be equal to or exceed the lesser of …
(I) 10 percent of the personnel-related costs for performance of the function; or

(ii)) $10,000,000

The potential savings forecasted above far exceed the $10 million threshold set by the statute, thereby supporting the adoption and use of these technologies.

Real Options Analysis

Risk Analysis and Real Options Valuation techniques allow a new way of approaching the problems of estimating return on investment (ROI) and the risk-value of various strategic real options. ROV technology was used to both provide preliminary analyses and build a strategy that is financially optimal and reduces the risks of financial losses in given circumstances and to provide flexibility in changing decisions when new information becomes available. An important point is that, in contrast, the traditional discounted cash flow (DCF) approach assumes a single decision pathway with fixed outcomes, and all decisions are made in the beginning without the ability to change over time. The strategic real options approach considers multiple decision pathways as a consequence of high uncertainty coupled with management's flexibility in choosing the optimal strategies or options along the way when new information becomes available. That is, management has the flexibility to make midcourse strategy corrections when there is uncertainty involved in the future. As information becomes available and uncertainty becomes resolved, management can choose the best strategies to implement.

Target points of analysis:

- The availability of new technology provides multiple pathways for the decision-making process.
- ROV techniques provide flexibility for the decision-making process.
- It provides a quantitative approach for the decision-making process.
- It can minimize financial risk in the undertaken project.

Following are the assumptions that could be altered later in the model to increase accuracy:

- All calculations are in $1,000.00.

- There are three major categories by which production is analyzed and optimized:
  - High complexity of production
  - Medium complexity of production
  - Low complexity of production
- Base Case is assumed to be 25% of in-house production.

Figure 23 demonstrates the basic calculations of estimating the costs and benefits of different scenarios of production versus outsourcing. The production rates reflect two extreme strategies and three shared-production strategies.

The cost-estimating equation, Cost = Benefits / (ROI + 1), was used with the benefits and Returns on Investment (Figure 22) to estimate the costs of each make/buy strategy.

Benefits were estimated by multiplying the production rates by the average parts values.

Average Part Values in $1000

High	$6.00
Medium	$3.00
Low	$1.00

Annual Production Rate Estimates of Five Make-Buy Strategies

% Made by Navy	High Complexity 25%		Medium Comp. 50%		Low Complexity 25%		Parts Produced		
	Industry	Navy	Industry	Navy	Industry	Navy	Industry	Navy	Total
0%	6,750		13,500		6,750		27,000		27,000
25%		6,750	13,500		6,750		20,250	6,750	27,000
50%		6,750	6,750	6,750	6,750		13,500	13,500	27,000
75%		6,750		13,500	6,750		6,750	20,250	27,000
100%		6,750		13,500		6,750		27,000	27,000

Estimated Annual Costs of Five Make-Buy Strategies

% Made by Navy	High Complexity 25%		Medium Comp. 50%		Low Complexity 25%		Parts Produced		
	Industry	Navy	Industry	Navy	Industry	Navy	Industry	Navy	Total
0%	6,022		16,109		6,022		28,153		28,153
25%		3,319	16,109		6,022		22,131	3,319	25,450
50%		3,319	6,022	3,319	6,022		12,044	6,638	18,682
75%		3,319		8,841	6,022		6,022	12,160	18,182
100%		3,319		8,841		3,319		15,479	15,479

Savings at the depot studied by having the Navy instead of industry produce all parts (in $1000): $ 12,674

Estimated Annual Benefits of Five Make/Buy Strategies

% Made by Navy	High Complexity 25%		Medium Comp. 50%		Low Complexity 25%		Parts Produced		
	Industry	Navy	Industry	Navy	Industry	Navy	Industry	Navy	Total
0%	40,500		40,500		6,750		87,750		87,750
25%		40,500	40,500		6,750		47,250	40,500	87,750
50%		40,500	20,250	20,250	6,750		27,000	60,750	87,750
75%		40,500		40,500	6,750		6,750	81,000	87,750
100%		40,500		40,500		6,750		87,750	87,750

Figure 23. Assumptions Used for Calculation of Costs and Benefits

Monte Carlo Risk Simulation was used to create artificial futures by generating hundreds of thousands of sample paths of outcomes and analyzing their prevalent characteristics. In the Monte Carlo simulation process, Triangular distribution was used as the base case. Figure 24 shows the values for a sample distributional spread used in Monte Carlo Risk Simulations per the AFCAA handbook as described previously.

Part Values	Min	Likely	Max
High	$0.852	$6.000	$11.148
Medium	$0.426	$3.000	$5.574
Low	$0.142	$1.000	$1.858

Figure 24. Points Used for Triangular Distribution in the Simulation Process

ROV methodology is used in

- Identifying different investment decision pathways that management can navigate given the highly uncertain conditions.
- Valuing each of the strategic decision pathways and what it represents in terms of financial viability and feasibility.
- Prioritizing these pathways or projects based on a series of qualitative and quantitative metrics.
- Optimizing the value of strategic investment decisions by evaluating different decision paths under certain conditions or determining how using a different sequence of pathways can lead to the optimal strategy.
- Managing existing and developing new strategic decision pathways for future opportunities.

As illustrated in Figure 25, four major strategies were identified and solved using ROV SLS technology as options for the decision-making process concerning planning for further action.

- Strategy A: Base case. Keep purchasing vast majority of Inventory. This is a risky strategy. Opportunity losses are occurring due to missed financial savings and control over the process in the long run.
- Strategy B: Oursource. Buy All 100%: Outsource all manufacturing to outside contractors. This strategy is risky because it leads to dependency on organizations that are outside the control of the Navy.
  - Open Architecture. To reduce the risk of dependency on a few vendors, the Navy could implement an Open Architecture principle that provides interchangeability of critical parts on a ship without any loss of functionality. That gives the Navy the flexibility to choose vendors based on objective parameters (price, frequency, availability).
  - Exit. This Strategy is not expensive to abandon. The Navy can easily go to other options without any substantial costs.
- Strategy C: Insource. Make All 100%: This is the option to manufacture everything “in-house” immediately. The ROI is high but the cost and risks are very high if it does not work out.
  - Invest 100%. Pros: savings may be captured by the use of 3DLST, 3DP, and CPLM for fleet maintenance and modernization. Cons: high costs and risks of immediate in-sourcing.
  - Exit. This option is very costly to abandon because of the high investment costs.
- Strategy D: Sequential Compound Option
  - Phase I. 25% PLM: Implement PLM. This is a strategic business approach applying a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise.
  - Phase II. 50%: 3D Laser Scanning Technology. This is a small-scale investment over time with the ability to exit and walk away should the technology not work out as expected. Phasing

investments over time hedges any downside risks and reduces any risks of large lump-sum investments.

- Exit. This technology could still be useful for other Options.
- Phase III. 75%: Additive Manufacturing. This includes 3D CAD models, Conversion to Stereo-lithography STL, Revision of STL Models, AM Machine Setup and implementation.
- Exit. 3D Technology could be still applied in other operations of the Navy.
- Phase IV. 100%: Final Phase. Implement the PLM, 3DLST technology for all required inventory parts. At this point the project is too costly to abandon. The Navy will choose to implement the technology limited to the most critical parts of its operations.

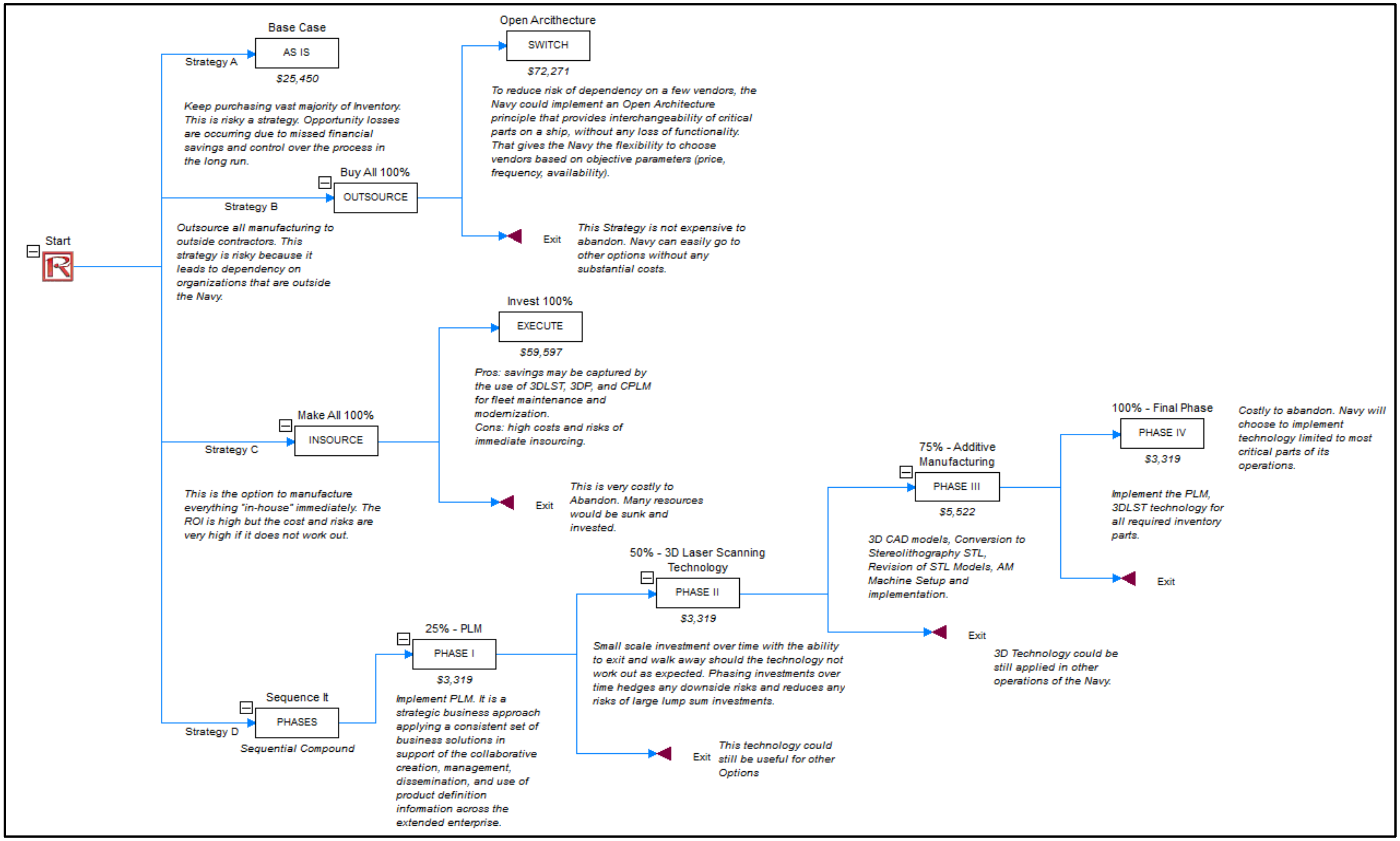

Figure 25. Schema of Four Strategies

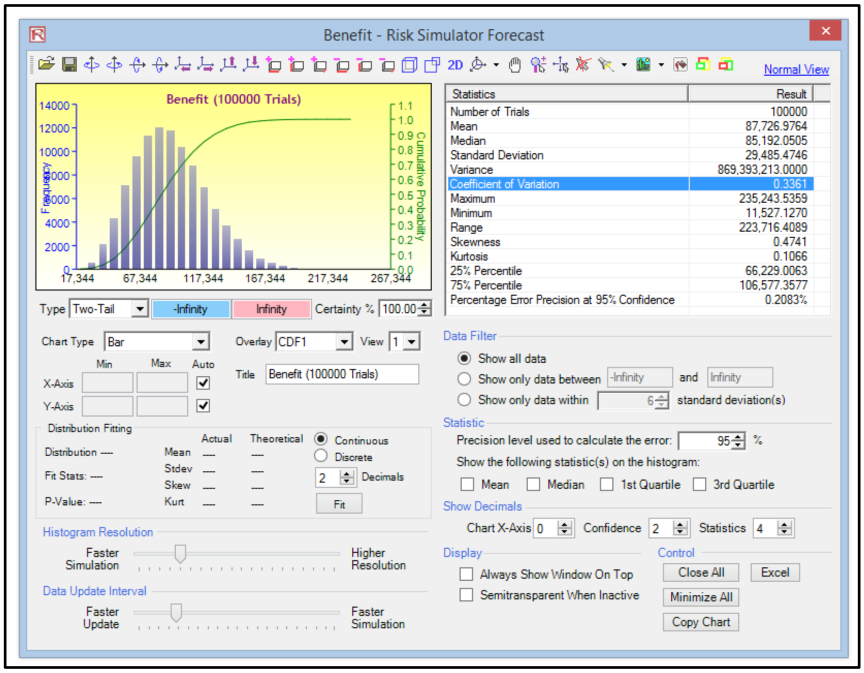

Figure 26. RS Monte Carlo Simulation Results Window

To calculate Volatility for use in the Real Option Valuation process, Risk Simulator was used. Monte Carlo simulation was applied for estimating Volatility. Figure 23 illustrates six different input assumptions (green cells) with output being estimated as the annual benefit of total production of the parts (yellow cell). The result is shown in Figure 26. The Coefficient of Variation of 33.61% for the High Risk and 23.62% for the Medium Risk AFCAA settings are the volatilities used in the analyses.

Additional variables that were used in ROV SLS calculations include the Rate of 10-year Treasury Bonds as a base for Risk-Free Rate, the number of steps in the binomial calculations, and the number of years in the time line for the life of the option (Figure 27).

Simulated Risk	Volatility
Medium Risk	23.62%
High Risk	33.61%

Additional Variables	Inputs
Risk-Free Rate	1.63%
Steps	100
Years	12

Figure 27. SLS Inputs

Calculations performed by ROV SLS software (Figure 28) illustrate that the Strategy D—Sequential Compound Option is the most obvious choice with the highest total strategic value.

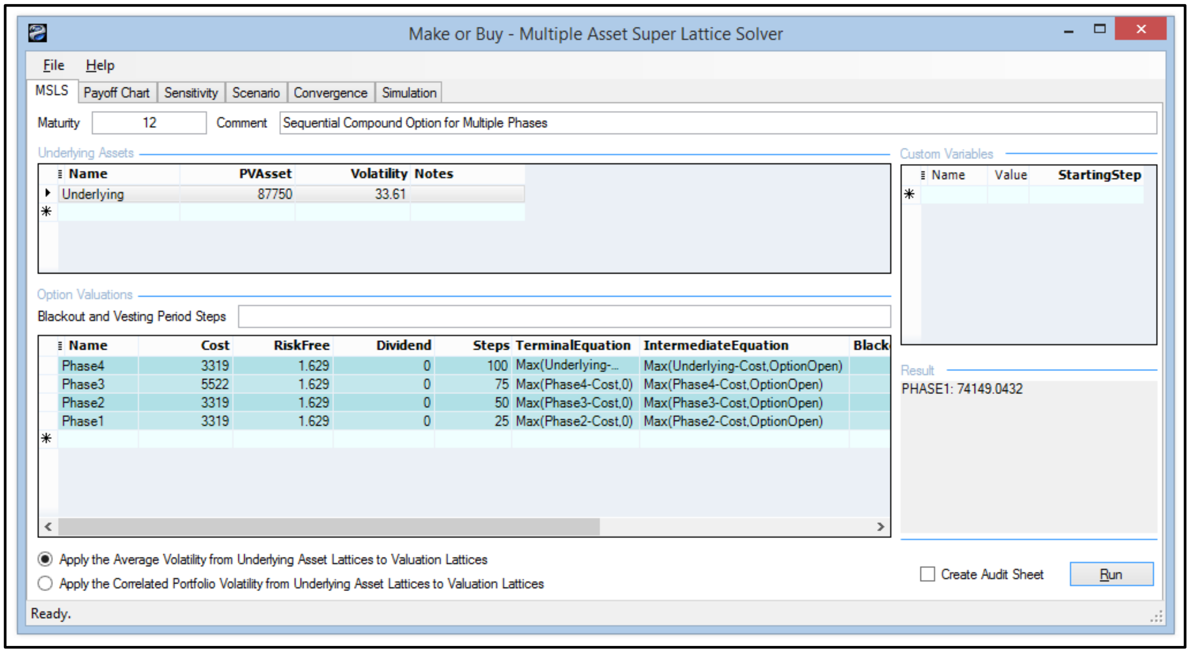

Figure 28. ROV SLS Inputs

The results (Figure 29) show that Strategy D has the highest value. This Sequential Compound Option involves implementing new technologies in phases, thus giving management the ability to exit at any stage of the project while minimizing the risk of losses.

Strategy Path	Decision	Strategic Value	Notes
Strategy A	25% Navy As-Is	62,300	AS-IS 25%
Strategy B	Buy 100%	59,597	Buy 100%
Strategy C	Make 100%	72,271	Make 100%
Strategy D	Phased	74,149	Stepwise

Phases	Cost	Timing
Phase 1 Cost	3,319	2 Years
Phase 2 Cost	3,319	4 Years
Phase 3 Cost	5,522	6 Years
Phase 4 Cost	3,319	8 Years
Total Costs	15,479	

Figure 29. Results (in $ Millions)

It has now become evident that the U.S. Navy leadership can take advantage of more advanced analytical procedures when making strategic investment decisions and when managing portfolios of projects. In the past, due to the lack of technological maturity, businesses and the government had to resort to relying on experience and managing by gut feel. Now, with the assistance of technology and more mature methodologies, analysis can be taken a step further. The only barrier to implementation, simply put, is the lack of exposure to the potential benefits of the methods. In order to be ready for the challenges of the 21st century, and to create a highly effective and efficient force, strategic real options and risk analysis are available to aid leadership with critical decision making.

Conclusions and Recommendations

The current work investigated the potential of three emerging technologies (3D Printing Operations, 3D Laser Scanning Technology, and Collaborative Product Lifecycle Management) to generate cost saving in US Naval ship maintenance and modernization. The challenges posed by fleet maintenance and modernization and an introduction to in-sourcing and its history within the US federal government were described as a context for the work. An extensive introduction to the three technologies was followed by a description of the research approach and methods. Then cost savings using the technologies under different in-sourcing (make/buy) scenarios were estimated. Real options were used to investigate several in-sourcing versus outsourcing alternatives. The results of these analyses are the basis for recommendations for practice.

Potential cost savings due to the adoption and use of the three technologies was estimated to increase as more parts were manufactured by the US Navy (i.e., insourced), with savings over $12 million annually if all parts were insourced. In-house manufacture of complex parts was found to generate the largest savings. In combination with other research this suggests that complex parts for which few copies are needed are the best candidates for initial in-sourcing using the technologies.

Of the four make/buy strategies analyzed, Strategy D of the phased implementation approach has the highest strategic value. This strategy involves implementing new technologies in phases, thus giving management the ability to exit at any stage of the project, while minimizing the risk of losses.

The results have several significant implications for fleet maintenance and modernization practice. The finding of significant potential savings with in-sourcing suggests that the three technologies have created a potential shift in the optimal acquisition modes for fleet parts. Based on the Rand model of in-sourcing and outsourcing acquisition, as the costs of producing few more different types of parts (e.g., simple vs complex and frequent vs. rare) drop with the new technologies, the Navy will be able to capture more benefits by in-sourcing more parts. This concept is shown in Figure 30 as a shift from the dashed lines to the solid lines that include a larger portfolio of parts.

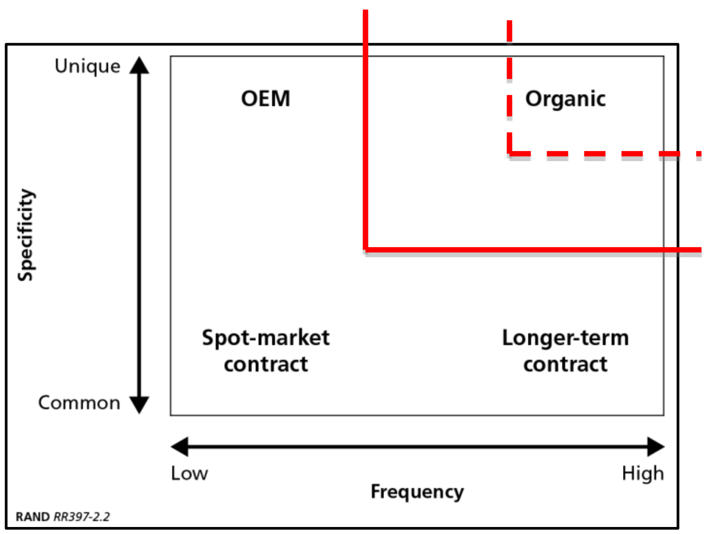

Figure 30. Based on Conceptual Sourcing Framework
(Drew, McGarvey, & Buryk, 2013)

Recommendations include that the US Navy should

- adopt the three technologies investigated,
- test in-sourcing with these technologies starting with low volume complex products, and
- plan to increase the scale of in-sourcing after developing processes and a track record to justify expansion.
- Work to change acquisition regulations and procedures that impede the use of in-sourcing for parts manufacturing.

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References

American Federation of Government Employees (2014). Defcon 2014 fact sheet on in-sourcing. Retrieved from https://www.afge.org/?documentID=3975

Aronowitz, J. (2012, March 29). Contractors: How much are they worth: Hearing before the Subcommittee on Contracting Oversight, Committee on Homeland Security and Governmental Affairs, Senate. 112th Cong 2 (2012) (testimony of Jay D. Aronowitz). Retreived from http://www.gpo.gov/fdsys/pkg/CHRG-112shrg73681/html/CHRG-112shrg73681.htm

Brodsky, R. (2011, February 3). Army suspends all ongoing in-sourcing plans. *Government Executive*. Retreived from http://www.govexec.com/defense/2011/02/army-suspends-all-ongoing-insourcing-plans/33242/

Business Coalition for Fair Competition (BCFC). (2011). Letter to the Honorable Howard McKeon, Chairman Committee on Armed Services. Retreived from http://www.governmentcompetition.org/uploads/BCFC_Letter_to_Chairman_Buck_McKeon-Insourcing-4-11-2011.pdf

Caffrey, T., & Wohlers, T. (2014, June). 3D printing builds up its manufacturing resume. *Manufacturing Engineering.* Retreived from http://www.sme.org/MEMagazine/Article.aspx?id=80916

CIMdata. (2007). All about PLM. Retrieved from https://www.cimdata.com/en/resources/about-plm

Cotteleer M, Holdowsky, J., and Mahtoe, M. (2013) The 3D opportunity primer: The basics of additive manufacturing. Retreived from http://d2mtr37y39tpbu.cloudfront.net/wp-content/uploads/2014/03/DUP_718-Additive-Manufacturing-Overview_MASTER1.pdf

Cullom, P. (2014, July 15). 5 things to know about Navy 3D printing. Retreived from http://navylive.DODlive.mil/2014/07/15/5-things-to-know-about-navy-3d-printing/

Department of the Navy, Highlights of the Department of the Navy FY 2015 Budget, http://www.finance.hq.navy.mil/fmb/15pres/Highlights_book.pdf

Drew, J., McGarvey, R., & Buryk, P. (YEAR). *Enabling early sustainment decisions, application to F-35 depot-level maintenance* (RR-397-AF). Santa Monica, CA: RAND.

Fleet Industrial Supply Center Puget Sound Business Support Office. (2009, April 2). FISC Puget Sound saves millions in contract conversion. Retrieved from http://www.navy.mil/submit/display.asp?story_id=43946

Ganderson, J. (2014, April 25). More of the same: Air Force prevails over another in-sourcing challenge. *Insourcing.* Retrieved from http://www.governmentcontractsadvisor.com/2014/04/25/air-force-insourcing-challenge/

Gartner. (2014). Gartner Says Consumer 3D Printing Is More Than Five Years Away. Retreived from http://www.gartner.com/newsroom/id/2825417.

General Electric . (2014, June 23). Fit to Print: New Plant Will Assemble World's First Passenger Jet Engine With 3D Printed Fuel Nozzles, Next-Gen Materials. Retrieved from http://www.gereports.com/post/80701924024/fit-to-print.

Gibson, I., Rosen, D. W., & Stucker, B. (2010). *Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital.* New York (NY): Springer Science+Business Media, LLC.

Goddard, C., Fireman, H., & Deegan, C. (2007, June). A question of cost. *Armed Forces Journal*. Retreived from https://acc.dau.mil/adl/en-US/155497/file/29364/ARMED%20FORCES%20JOURNAL%20-%20A%20question%20of%20cost%20-%20June%202007.pdf

Goldman Sachs Global Investment Research (2013, August). The search for creative destruction. Retreived from http://www.lefabshop.fr/wp-content/uploads/2013/08/159064311-2013-08-07-Goldman-Sachs-United-States-the-Search-for-Creative-Destruction-64118432.pdf

Government Accountability Office (GAO). (2012, February). *DOD needs to better oversee in-sourcing data and align in-sourcing efforts with strategic workforce plans* (GAO-12-319). Washington, DC: Author.

Government Accountability Office (GAO). (1997, July). *Internal Revenue Service: Issues affecting IRS' private debt collection* (GGD-97-129R). Retrieved from http://www.gao.gov/assets/90/86658.pdf

Government Accountability Office (GAO). (2004, May). *Tax debt collection: IRS is addressing critical success factors for contracting out but will need to study the best use of resources* (GAO-04-49). Report to Congressional Requesters. Washington, DC: Author.

Greaves, T., & Jenkins, B. (2007). 3D laser scanning market red hot: 2006 industry revenues $253 million, 43% growth. *SparView, 5*(7). Retrieved from http://www.sparllc.com/archiveviewer.php?vol=05&num=07&file=vol05no07-01

Halchin, E. (2012, February 7). *Sourcing policy: Selected developments and issues*, Congressional Research Service Report R42341). Retreived from http://fas.org/sgp/crs/misc/R42341.pdf

Halpern, M., & Smith, M. (2004, December 29). *Total value of opportunity analysis exposes value of PLM* (Gartner Group Report).

Kenney, M. (2013). *Cost reduction through the use of additive manufacturing (3D printing) and collaborative product life cycle management technologies to enhance the Navy's maintenance programs* (Master's thesis). Monterey, CA: Naval Postgraduate School.

Kronsberg, Matthew (2013) "3-D Printing for All" Wall Street Journal, Oct. 20, 2013. p D14.

Lipson, H., & Kurman, M. (2013). *Fabricated: The New World of 3D Printing.* Somerset (NJ): Wiley.

Lundquist, E. (2013, July 1). U.S. Navy maintenance and modernization suffer due to budget woes. *Defenseweek.*

Lipowicz, A. (2011, February 22). Converting contract IT workers to employees saved $27M, official says. *Federal Computer Week*.

Mackley, C. J. (2014, March). *Reducing costs and increasing productivity in shop maintenance using product lifecycle management, 3D laser scanning, and 3D printing* (Master's thesis). Monterey, CA: Naval Postgraduate School.

Manuel, K., & Maskell, J. (2013, February 22). *In-sourcing functions performed by federal contractors: Legal issues.* Congressional Research Service Report R42341). Retreived from http://fas.org/sgp/crs/misc/R41810.pdf

Marquis, K. (2011). *In-sourcing and outsourcing for U.S. Department of Defense IT projects: A model*. Retreived from www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA549027

Mitchell, Robert L. (2014, August 13).l 3D printing makes its move into production. Computerworld. Retrieved from http://www.computerworld.com/article/2490930/enterprise-applications-3d-printing-makes-its-move-into-production.html

National Shipbuilding Research Program Advanced Shipbuilding Enterprise (NSRP ASE). (2007). *NSRP ASE ship check data capture follow-on project results.* Retrieved from http://www.nsrp.org/projects/deliverables/ase_505001.pdf

National Shipbuilding Research Program Advanced Shipbuilding Enterprise (NSRP ASE). (2006). *NSRP ASE ship check project* (Technical No. NSRP 04-01-08). Retrieved from http://www.nsrp.org/panels/bpt/downloads/ShipCheck1205.pdf

Naval Surface Warfare Centere (NSWC), (2013) Port Hueneme Division. Distance support: Distance support in depth. Retrieved from http://www.navsea.navy.mil/nswc/porthueneme/whatWeDo/distanceSupport/inDepth.aspx

Office of the Assistant Secretary of Defense (Logistics and Materiel Readiness). (2013). *DOD maintenance 2013 factbook*. Retrieved from http://www.acq.osd.mil/log/mpp/factbooks/Fact_Book_2013_10-15-2013_Final_ecopy.pdf

Office of the Under Secretary of Defense for Personnel and Readiness Requirements and Strategic Integration Directorate. (2011). *Report to the Congressional Defense Committees on the Department of Defense's FY 2010 In-Sourcing Actions*. Retrieved from http://www.inthepublicinterest.org/article/report-congressional-defense-committees-department-defenses-fy-2010-sourcing-actions

PricewaterhouseCooper PwC. (2014). 3-D Printing and the new shape of industrial manufacturing: Chart Pack. Retrieved from http://www.pwc.com/us/en/industrial-products/assets/3d-printing-next_manufacturing-chart-pack-pwc.pdf.

Reuters. (2013). World in nano [Slideshow]. Retrieved from http://www.reuters.com/news/pictures/slideshow?articleId=USRTR304C2#a=1.

Schindler, C. (2010). *Product lifecycle management: A collaborative tool for defense acquisitions* (Master's thesis). Monterey CA: Naval Postgraduate School.

U.S. Department of Transportation (USDT). (2009, August 14). FAA Tech Center in-sourcing saves between $52 and $203 million in data system costs. Retrieved from http://usdotblog.typepad.com/secretarysblog/2009/08/faa-tech-center-in-sourcing-saves-between-52-and203-million-in-data-system-costs.html#.VEgHuGfRppF

U.S. Postal Service Office of Inspector General. (2013, July 7). If It Prints, It Ships: 3D Printing and the Postal Service. Retrieved from https://www.uspsoig.gov/sites/default/files/document-library-files/2014/rarc-wp-14-011_if_it_prints_it_ships_3d_printing_and_the_postal_service.pdf.

Weisgerber, M. (2014, September 29). The defense industry is expanding the use of 3D printing. *Defense One*. Retrieved from http://www.defenseone.com/technology/2014/09/defense-industry-expanding-use-3d-printing/95396/

Wile, Rob (2013). Credit Suisse: 3D printing is going to be way bigger than what the 3d printing companies are saying. Retreived from: http://www.businessinsider.com/the-3-d-printing-market-will-be-huge-2013-9

Williams, Lauren Evette (2011). An analysis of federal agency policies for the department of defense insourcing initiative (Master's thesis). Atlanta, GA.

Wohlers Associates, Inc. (2013). Retrieved from http://wohlersassociates.com/brief07-10.htm

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Appendix A. Memorandum on In-Sourcing

OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE
4000 DEFENSE PENTAGON
WASHINGTON, D.C. 20301-4000

READINESS AND FORCE MANAGEMENT

JAN 29 2013

MEMORANDUM FOR: SEE DISTRIBUTION

SUBJECT: Private Sector Notification Requirements in Support of In-sourcing Actions

This memorandum provides implementing direction on the notification of private sector providers (contractors) when making a determination to in-source a contracted service for civilian or military performance. This guidance is issued in accordance with section 2463 of title 10, United States Code, as amended by section 938 of the National Defense Authorization Act for Fiscal Year 2012, Public Law 112-81, and is intended to supplement existing policies related to section 2463 and in-sourcing. This guidance is effective upon issuance, and is not applicable retroactively.

The leadership of each Component, organization, or command shall determine and document final decisions to in-source. Within 20 business days of the receipt of such decision, the contracting officer shall provide a written notification to affected incumbent private sector providers. No formal hiring or contract related actions may be initiated prior to such notification, except for preliminary internal actions associated with hiring or contract modification. Notifications issued by contracting officers to affected private sector providers may summarize, in an appropriate format, the requiring official's final determination as to why the service is being in-sourced and shall be coordinated with the Component's in-sourcing program official. Component in-sourcing program officials may delegate the coordination of the notification statement as noted above. Whenever possible, determinations to in-source should be made so as to align with contracting decisions, for example to preclude exercising option periods or re-competitions of expiring contracts. Simultaneously, to meet the statutory requirement to provide notifications to the Congressional defense committees, Component's in-sourcing program officials shall provide copies of all notifications, via email, to the points of contact provided below. This office will provide them to the Congressional defense committees on a quarterly basis.

The Department greatly values the support provided by private sector firms and recognizes that the contractors are, and will continue to be, a vital source of expertise, innovation, and support to the Department's Total Force. However, in-sourcing continues to be an important, effective, and necessary workforce shaping tool to appropriately align inherently governmental activities to government performance; perform functions more efficiently and effectively; and protect the public's interest while providing the best value for taxpayers.

In-sourcing of contracted services falls into three categories of justification - work that is determined, as it is being executed, to be:

1) Inherently Governmental Functions: Consistent with statutes and policy, Components should take immediate action to in-source (or divest) work performed under contract that is determined to be inherently governmental as defined in

Office of Federal Procurement Policy (OFPP) Policy Letter 11-01, "Performance of Inherently Governmental and Critical Functions" (available at: http://www.gpo.gov/fdsys/pkg/FR-2011-09-12/pdf/2011-23165.pdf).

2) Work Closely Associated with Inherently Governmental Functions, Critical in Nature, and Unauthorized Personal Services: Consistent with section 2463 of title 10, United States Code; OFPP Policy Letter 11-01; and DoD Instruction 1100.22, "Policy and Procedures for Determining Workforce Mix", some work that, while not inherently governmental (including many non-inherently governmental acquisition functions), may not be appropriate for continued performance by the private sector (for example: to mitigate risk, ensure continuity of operations, build internal capability, meet and/or maintain readiness). In certain instances, increased management control and oversight of such work, modifications to the statement of work or changes to how services are performed may be appropriate in lieu of in-sourcing. In instances where in-sourcing (or divestiture) is determined to be appropriate Components should take action expeditiously.

3) Cost-Based In-sourcing Decisions: Contracted services may be in-sourced if the work is determined to be cost effectively delivered by civilians, based on a cost analysis conducted in accordance with Directive-Type Memorandum (DTM) 09-007, "Estimating and Comparing the Full Costs of Civilian and Military Manpower and Contractor Support" (or successor guidance), provided the conversion differential required under section 2463 of title 10, United States Codes is met.

The Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics will incorporate the requirements for notification set forth in this memorandum into the Defense Federal Acquisition Regulation Supplement. Additionally, the requirements set forth in this memorandum will be incorporated in a future DoD issuance on in-sourcing. Components may issue, after appropriate coordination with this office, supplemental guidance regarding in-sourcing of contracted services and/or related notification requirements.

Please ensure maximum distribution of this memorandum across your organization. Questions regarding application and implementation of this memorandum to in-sourcing actions should be addressed to the following points of contact within the Office of Total Force Planning & Requirements: Mr. Thomas Hessel (thomas.hessel@osd.mil or 703-697-3402) and Ms. Amy Parker (amy.parker@osd.mil or 703-697-1735).

Frederick Vollrath
Principal Deputy Assistant Secretary of Defense
(Readiness and Force Management)
Performing the Duties of the Assistant
Secretary of Defense (Readiness and Force
Management)

Appendix B. A Primer on Risk Simulation, Return on Investment, Strategic Real Options, and Portfolio Optimization—Integrated Risk Management5

Since the beginning of recorded history, games of chance have been a popular pastime. Even in Biblical accounts, Roman soldiers cast lots for Christ's robes. In earlier times, chance was something that occurred in nature, and humans were simply subjected to it as a ship is to the capricious tosses of the waves in an ocean. Even up to the time of the Renaissance, the future was thought to be simply a chance occurrence of completely random events and beyond the control of humans. However, with the advent of games of chance, human greed has propelled the study of risk and chance to ever more closely mirror real-life events. Although these games were initially played with great enthusiasm, no one actually sat down and figured out the odds. Of course, the individual who understood and mastered the concept of chance was bound to be in a better position to profit from such games of chance.

It was not until the mid-1600s that the concept of chance was properly studied, and the first such serious endeavor can be credited to Blaise Pascal, one of the fathers of the study of choice, chance, and probability. Fortunately for us, after many centuries of mathematical and statistical innovations from pioneers such as Pascal, Bernoulli, Bayes, Gauss, LaPlace, and Fermat, and with the advent of blazing fast computing technology, our modern world of uncertainty can be explained with much more elegance through methodological rigorous hands-on applications of risk and uncertainty. Even as recent as two and a half decades ago, computing technology was only in its infancy and running complex and advanced analytical models would have seemed a fantasy, but today, with the assistance of more powerful and enabling software packages, we have the ability to practically apply such techniques with great ease. For this reason, we have chosen to learn from human history that with innovation comes the requisite change in human behavior to apply these new methodologies as the new norm for rigorous risk-benefit analysis.

To the people who lived centuries ago, risk was simply the inevitability of chance occurrence beyond the realm of human control. Albeit many phony soothsayers profited from their ability to convincingly profess their clairvoyance by simply stating the obvious or reading the victims' body language and telling them what they wanted to hear. We modern-day humans, ignoring for the moment the

[5] This primer is written by Dr. Johnathan Mun, and is based on his two latest books, *Modeling Risk*, Second Edition (Wiley, 2010) and *Real Options Analysis,* Second Edition (Wiley, 2006).

occasional seers among us, with our fancy technological achievements, are still susceptible to risk and uncertainty. We may be able to predict the orbital paths of planets in our solar system with astounding accuracy or the escape velocity required to shoot a man from the Earth to the Moon, or drop a smart bomb within a few feet of its target thousands of miles away, but when it comes to, say, predicting a firm's revenues the following year, we are at a loss. Humans have been struggling with risk our entire existence, but through trial and error, and through the evolution of human knowledge and thought, have devised ways to describe, quantify, hedge, and take advantage of risk.

In the U.S. Military context, risk analysis, real options analysis, and portfolio optimization techniques are enablers of a new way of approaching the problems of estimating return on investment (ROI) and estimating the risk-value of various strategic real options. There are many new Department of Defense (DOD) requirements for using more advanced analytical techniques. For instance, the Clinger-Cohen Act of 1996 mandates the use of *portfolio management* for all federal agencies. The Government Accountability Office's "Assessing Risks and Returns: A Guide for Evaluating Federal Agencies' IT Investment Decision-Making," Version 1 (February 1997) requires that IT investments apply ROI measures. DOD Directive 8115.01 issued October 2005 mandates the use of performance metrics based on outputs, with ROI analysis required for all current and planned IT investments. DOD Directive 8115.bb (expected approval in late 2006) implements policy and assigns responsibilities for the management of DOD IT investments as portfolios within the DOD Enterprise where they defined a portfolio to include outcome performance measures and an expected return on investment. The DOD Risk Management Guidance Defense Acquisition guide book requires that alternatives to the traditional cost estimation need to be considered because legacy cost models tend not to adequately address costs associated with information systems or the risks associated with them.

In this quick primer, advanced quantitative risk-based concepts will be introduced, namely, the hands-on applications of Monte Carlo simulation, real options analysis, stochastic forecasting, portfolio optimization, and knowledge value added. These methodologies rely on common metrics and existing techniques (e.g., return on investment, discounted cash flow, cost-based analysis, and so forth), and complements these traditional techniques by pushing the envelope of analytics, and not to replace them outright. It is not a complete change of paradigm, and we are not asking the reader to throw out what has been tried and true, but to shift one's paradigm, to move with the times, and to *improve* upon what has been tried and true. These new methodologies are used in helping make the best possible decisions, allocate budgets, predict outcomes, create portfolios with the highest strategic value and returns on investment, and so forth, where the conditions surrounding these decisions are risky or uncertain. They can be used to identify, analyze, quantify, value, predict, hedge, mitigate, optimize, allocate, diversify, and manage risk for military options.

Why Is Risk Important in Making Decisions?

Before we embark on the journey to review these advanced techniques, let us first consider why risk is critical when making decisions, and how traditional analyses are inadequate in considering risk in an objective way. Risk is an important part of the decision-making process. For instance, suppose projects are chosen based simply on an evaluation of returns alone or cost alone; clearly the higher-return or lower-cost project will be chosen over lower-return or higher-cost projects.

As mentioned, projects with higher returns will in most cases bear higher risks. And those projects with immediately lower returns would be abandoned. In those cases, where return estimates are wholly derived from cost data (with some form of cost in the numerator and denominator of ROI), the best thing to do is reduce all the costs, that is, never invest in new projects. The result of this primary focus on cost reduction is a stifling of innovation and new ways of doing things. The goal is not simply cost reduction. In this case, the simplest approach is to fire everyone and sell off all the assets. The real question that must be answered is how cost compares to desired outputs, that is, "cost compared to what?"

To encourage a focus on improving processes and innovative technologies, a new way of calculating return on investment that includes a unique numerator is required. ROI is a basic productivity ratio that requires unique estimates of the numerator (i.e., value, revenue in common units of measurement) and the denominator (i.e., costs, investments in dollars). ROI estimates must be placed within the context of a longer term view that includes estimates of risk and the ability of management to adapt as they observe the performance of their investments over time.

Therefore, instead of relying purely on immediate ROIs or costs, a project, strategy, process innovation, or new technology should be evaluated based on its total strategic value, including returns, costs, and strategic options, as well as its risks. Figures B1 and B2 illustrate the errors in judgment when risks are ignored. Figure B1 lists three *mutually exclusive* projects with their respective costs to implement, expected net returns (net of the costs to implement), and risk levels (all in present values).[6] Clearly, for the budget-constrained decision maker, the cheaper the project the better, resulting in the selection of Project X. The returns-driven

[6] Risks can be computed many ways, including volatility, standard deviation of lognormal returns, value at risk, and so forth. See *Modeling Risk*, by Johnathan Mun (Wiley, 2005) for more technical details.

decision maker will choose Project Y with the highest returns, assuming that budget is not an issue. Project Z will be chosen by the risk-averse decision maker as it provides the least amount of risk while providing a positive net return. The upshot is that, with three different projects and three different decision makers, three different decisions will be made. Who is correct and why?

Why is Risk Important?

Name of Project	Cost	Returns	Risk
Project X	$50	$50	$25
Project Y	$250	$200	$200
Project Z	$100	$100	$10

Project X for the cost and budget-constrained manager
Project Y for the returns driven and nonresource-constrained manager
Project Z for the risk-adverse manager
Project Z for the smart manager

Figure B1. Why Is Risk Important?

Figure B2 shows that Project Z should be chosen. For illustration purposes, suppose all three projects are independent and mutually exclusive, and that an unlimited number of projects from each category can be chosen but the budget is constrained at $1,000. Therefore, with this $1,000 budget, 20 project Xs can be chosen, yielding $1,000 in net returns and $500 risks, and so forth. It is clear from Figure B2 that project Z is the best project as for the same level of net returns ($1,000), the least amount of risk is undertaken ($100). Another way of viewing this selection is that for each $1 of returns obtained, only $0.1 amount of risk is involved on average, or that for each $1 of risk, $10 in returns are obtained on average. This example illustrates the concept of *bang for the buck* or getting the best value (benefits and costs both considered) with the least amount of risk. An even more blatant example is if there are several different projects with identical single-point average net benefit or cost of $10 million each. Without risk analysis, a decision maker should be, in theory, indifferent in choosing any of the projects. However, with risk analysis, a better decision can be made. For instance, suppose the first project has a 10% chance of exceeding $10 million, the second a 15% chance, and the third a 55% chance. Additional critical information is obtained on the riskiness of the project or strategy and a better decision can be made.

Adding an Element of Risk…

Looking at bang for the buck, X (2), Y (1), Z (10), Project Z should be chosen–with a $1,000 budget, the following can be obtained:

Project X: 20 Project Xs returning $1,000, with $500 risk
Project Y: 4 Project Xs returning $800, with $800 risk
Project Z: 10 Project Xs returning $1,000, with $100 risk

Project X: For each $1 return, $0.5 risk is taken
Project Y: For each $1 return, $1.0 risk is taken
Project Z: For each $1 return, $0.1 risk is taken

Project X: For each $1 of risk taken, $2 return is obtained
Project Y: For each $1 of risk taken, $1 return is obtained
Project Z: For each $1 of risk taken, $10 return is obtained

Conclusion:
Risk is important. Foregoing risks results in making the wrong decision.

Figure B2. Adding an Element of Risk

From Dealing with Risk the Traditional Way to Monte Carlo Simulation

Military and business leaders have been dealing with risk since the beginning of the history of war and commerce. In most cases, decision makers have looked at the risks of a particular project, acknowledged their existence, and moved on. Little quantification was performed in the past. In fact, most decision makers look only to single-point estimates of a project's benefit or profitability. Figure B3 shows an example of a single-point estimate.[7] The estimated net revenue of $30 is simply that, a single point whose probability of occurrence is close to zero.[8] Even in the simple model shown in Figure B3, the effects of interdependencies are ignored, and in traditional modeling jargon, we have the problem of *garbage-in, garbage-out* (GIGO). As an example of interdependencies, the units sold are probably negatively correlated to the price of the product, and positively correlated to the average variable cost; ignoring these effects in a single-point estimate will yield grossly incorrect results. There are numerous interdependencies in military options as well, for example, the many issues in logistics and troop movements beginning with the manufacturer all the way to the warrior in the field.

In the commercial example below, if the unit sales variable becomes 11 instead of 10, the resulting revenue may not simply be $35. The net revenue may actually decrease due to an increase in variable cost per unit while the sale price may

[7] We will demonstrate how KVA, combined with the traditional Market Comparables valuation method, allows for the monetization of benefits (i.e., revenue).
[8] On a continuous basis, the probability of occurrence is the area under a curve, e.g., there is a 90% probability revenues will be between $10 and $11 million. However, the area under a straight line approaches zero. Therefore, the probability of hitting exactly $10.0000 is close to 0.00000001%.

actually be slightly lower to accommodate this increase in unit sales. Ignoring these interdependencies will reduce the accuracy of the model.

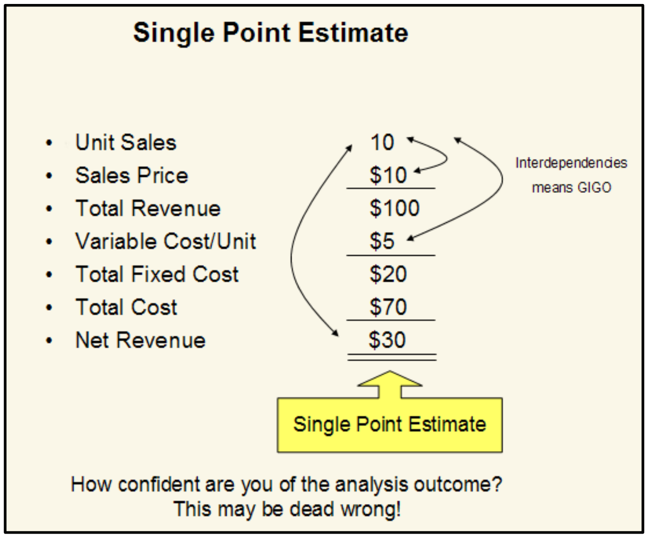

Figure B3. Single-Point Estimates

One traditional approach used to deal with risk and uncertainty is the application of scenario analysis. For example, scenario analysis is a central part of the capabilities-based planning approach in widespread use for developing DOD strategies. In the commercial example above, suppose three scenarios were generated: the worst-case, nominal-case, and best-case scenarios. When different values are applied to the unit sales, the resulting three scenarios' net revenues are obtained. As earlier, the problems of interdependencies are not addressed with these common approaches. The net revenues obtained are simply too variable. Not much can be determined from such an analysis.

In the military planning case, the problems are exacerbated by the lack of objective ways to estimate benefits in common units. Without the common-unit benefits analysis, it becomes difficult, if not impossible, to compare the net benefits of various scenarios. In addition, interdependencies must be interpreted in a largely subjective manner, making it impossible to apply powerful mathematical and statistical tools that enable more objective portfolio analysis. The problem arises for the top leaders in the DOD to make judgment calls, selection among alternatives (often referred to as "trades") about the potential benefits and risks of numerous projects and technologies investments

A related approach is to perform *what-if* or *sensitivity* analysis. Each variable is perturbed a prespecified amount (e.g., unit sales is changed ±10%, sales price is changed ±5%, and so forth) and the resulting change in net benefits is captured. This approach is useful for understanding which variables drive or impact the result the most. Performing such analyses by hand or with simple Excel spreadsheets is tedious and provides marginal benefits at best. A related approach that has the same goals but employs a more powerful analytic framework is the use of computer-modeled Monte Carlo simulation and tornado sensitivity analysis, where all perturbations, scenarios, and sensitivities are run hundreds of thousands of times automatically.

Therefore, computer-based Monte Carlo simulation, one of the advanced concepts introduced in this paper, can be viewed as simply an extension of the traditional approaches of sensitivity and scenario testing. The critical success drivers or the variables that affect the bottom-line variables the most, which at the same time are uncertain, are simulated. In simulation, the interdependencies are accounted for by using correlation analysis. The uncertain variables are then simulated tens of thousands of times automatically to emulate all potential permutations and combinations of outcomes. The resulting net revenues-benefits from these simulated potential outcomes are tabulated and analyzed. In essence, in its most basic form, simulation is simply an enhanced version of traditional approaches such as sensitivity and scenario analysis but automatically performed for thousands of times while accounting for all the dynamic interactions between the simulated variables. The resulting net revenues from simulation, as seen in Figure B4, show that there is a 90% probability that the net revenues will fall between $19.44 and $41.25, with a 5% worst-case scenario of net revenues falling below $19.44. Rather than having only three scenarios, simulation created 5,000 scenarios, or trials, where multiple variables are simulated and changing simultaneously (unit sales, sale price, and variable cost per unit), while their respective relationships or correlations are maintained.

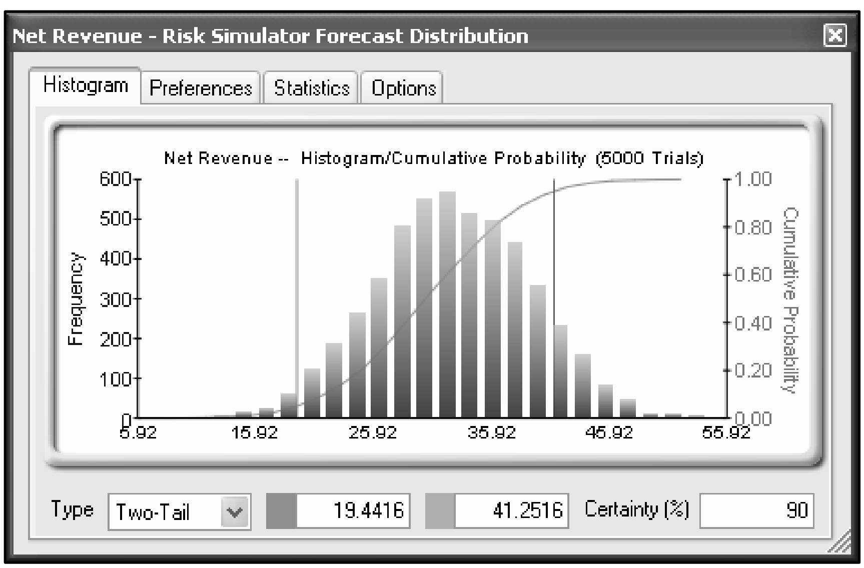

Figure B4. Simulation Results

Monte Carlo simulation, named for the famous gambling capital of Monaco, is a very potent methodology. For the practitioner, simulation opens the door for solving difficult and complex but practical problems with great ease. Perhaps the most famous early use of Monte Carlo simulation was by the Nobel physicist Enrico Fermi (sometimes referred to as the father of the atomic bomb) in 1930, when he used a random method to calculate the properties of the newly discovered neutron. Monte Carlo methods were central to the simulations required for the Manhattan Project, where in the 1950s Monte Carlo simulation was used at Los Alamos for early work relating to the development of the hydrogen bomb and became popularized in the fields of physics and operations research. The Rand Corporation and the U.S. Air Force were two of the major organizations responsible for funding and disseminating information on Monte Carlo methods during this time, and today there is a wide application of Monte Carlo simulation in many different fields including engineering, physics, research and development, business, and finance.

Simplistically, Monte Carlo simulation creates artificial futures by generating thousands and even hundreds of thousands of sample paths of outcomes and analyzes their prevalent characteristics. In practice, Monte Carlo simulation methods are used for risk analysis, risk quantification, sensitivity analysis, and prediction. An alternative to simulation is the use of highly complex stochastic closed-form mathematical models. For a high-level decision maker, taking graduate level advanced math and statistics courses is just not logical or practical. A well-informed analyst would use all available tools at his or her disposal to obtain the same answer the easiest and most practical way possible. And in all cases, when modeled correctly, Monte Carlo simulation provides similar answers to the more mathematically elegant methods. In addition, there are many real-life applications where closed-form models do not exist and the only recourse is to apply simulation methods. So, what exactly is Monte Carlo simulation and how does it work?

Monte Carlo simulation in its simplest form is a random number generator that is useful for forecasting, estimation, and risk analysis. A simulation calculates numerous scenarios of a model by repeatedly picking values from a user-predefined *probability distribution* for the uncertain variables and using those values for the model. As all those scenarios produce associated results in a model, each scenario can have a forecast. Forecasts are events (usually with formulas or functions) that you define as important outputs of the model.

Think of the Monte Carlo simulation approach as picking golf balls out of a large basket repeatedly with replacement. The size and shape of the basket depend on the distributional *input assumption* (e.g., a normal distribution with a mean of 100 and a standard deviation of 10, versus a uniform distribution or a triangular distribution) where some baskets are deeper or more symmetrical than others, allowing certain balls to be pulled out more frequently than others. The number of balls pulled repeatedly depends on the number of *trials* simulated. Each ball is indicative of an event, scenario, or condition that can occur. For a large model with multiple related assumptions, imagine the large model as a very large basket, wherein many baby baskets reside. Each baby basket has its own set of colored golf balls that are bouncing around. Sometimes these baby baskets are linked with each other (if there is a *correlation* between the variables), forcing the golf balls to bounce in tandem whereas in other uncorrelated cases, the balls are bouncing independently of one another. The balls that are picked each time from these interactions within the model (the large basket) are tabulated and recorded, providing a *forecast output* result of the simulation.

Knowledge Value Added Analysis

As the U.S. Military is not in the business of making money, referring to revenues throughout this paper may appear to be a misnomer. For nonprofit organizations, especially in the military, we require Knowledge Value Added (KVA), which will provide the required "benefits" or "revenue" proxy estimates to run ROI analysis. ROI is a basic productivity ratio with revenue in the numerator and cost to generate the revenue in the denominator (actually ROI is revenue-cost/cost). KVA generates ROI estimates by developing a market comparable price per common unit of output multiplied by the number of outputs to achieve a total revenue estimate.

KVA is a methodology whose primary purpose is to describe all organizational outputs in common units. It provides a means to compare the outputs of all assets (human, machine, information technology) regardless of the aggregated outputs produced. For example, the purpose of a military process may be to gather signal intelligence or plan for a ship alteration. KVA would describe the outputs of both processes in common units thus making their performance comparable.

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 assets (e.g., such as that produced by IT and humans). By capturing the value of knowledge embedded in an organization's core processes (i.e., employees and IT), KVA identifies the actual cost and revenue of a process, product, or service. Because KVA identifies every process required to produce an aggregated output in terms of the historical prices and costs per common unit of output of those processes, unit costs and unit prices can be calculated. The methodology has been applied in 45 areas within the DOD, from flight scheduling applications to ship maintenance and modernization processes.
As a performance tool, the KVA methodology:

- Compares all processes in terms of relative productivity
- Allocates revenues and costs 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

Based on the tenets of complexity theory, KVA assumes that humans and technology in organizations add value by taking inputs and changing them (measured in units of complexity) into outputs through core processes. The amount of change an asset within a process produces can be a measure of value or benefit. The additional assumptions in KVA include:

- Describing all process outputs in common units (e.g., using a knowledge metaphor for the descriptive language in terms of the time it takes an average employee to learn how to produce the outputs) allows historical revenue and cost data to be assigned to those processes historically.
- All outputs can be described in terms of the time required to learn how to produce them.
- Learning Time, a surrogate for procedural knowledge required to produce process outputs, is measured in common units of time. Consequently, Units of Learning Time = Common Units of Output (K).
- Common unit of output makes it possible to compare all outputs in terms of cost per unit as well as price per unit, because revenue can now be assigned at the suborganizational level.
- Once cost and revenue streams have been assigned to suborganizational outputs, normal accounting and financial performance and profitability metrics can be applied (Rodgers and Housel, 2006; Pavlou et. al., 2005; Housel and Kanevsky, 1995).

Describing processes in common units also permits market comparable data to be generated, particularly important for nonprofits like the U.S. Military. Using a market comparables approach, data from the commercial sector can be used to estimate price per common unit, allowing for revenue estimates of process outputs for nonprofits. This approach also provides a common units basis to 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 suborganizational level. KVA can rank processes by the degree to which they add value to the organization or its outputs. This ranking assists decision makers identify how much processes add value. Value is quantified in two key metrics: Return on Knowledge (ROK: revenue/cost) and ROI (revenue-investment cost/investment cost). The outputs from a KVA analysis become the input into the ROI models and real options analysis. By tracking the historical volatility of price and cost per unit as well as ROI, it is possible to establish risk (as compared to uncertainty) distributions, which is important for accurately estimating the value of real options.

The KVA method has been applied to numerous military core processes across the services. The KVA research has more recently provided a means for simplifying real options analysis for DOD processes. Current KVA research will provide a library of market comparable price and cost per unit of output estimates. This research will enable a more stable basis for comparisons of performance across core processes. This data also provides a means to establish risk distribution profiles for Integrated Risk Management approaches such as real options, and KVA currently is being linked directly to the Real Options Super Lattice Solver and Risk Simulator software for rapid adjustments to real options valuation projections.

Strategic Real Options Analysis

Suppose you are driving from point A to point B, and you only have or know one way to get there, a straight route. Further suppose that there is a lot of *uncertainty* as to what traffic conditions are like further down the road, and you *risk* being stuck in traffic, and there's a 50% chance that will occur. Simulation will provide you the 50% figure. But so what? Knowing that half the time you will get stuck in traffic is valuable information, but the question now is, so what? Especially if you have to get to point B no matter what. However, if you had several alternate routes to get to point B, you can still drive the straight route but if you hit traffic, you can make a left, right, or U-turn, to get around congestion, mitigating the risk, and getting you to point B faster and safer; that is, you have *options*. So, how much is such a strategic road map or global positioning satellite map worth to you? In military situations with high risk, real options can help you create strategies to mitigate these risks. In fact, businesses and the military have been doing real options for hundreds of years without realizing it. For instance, in the military, we call it *courses of action* or *analysis of alternatives*—do we take Hill A so that it provides us the option and ability to take Hill B and Valley C, or how should we take Valley C or do we avoid taking Valley C altogether, and so forth. A piece that is missing is the more formal structure and subsequent analytics that real options analysis provides. Using real options analysis, we can quantify and value each strategic pathway, and frame strategies that will hedge or mitigate, and sometimes take advantage of, risk.

In the past, corporate investment decisions were cut-and-dried. Buy a new machine that is more efficient, make more products costing a certain amount, and if the benefits outweigh the costs, execute the investment. Hire a larger pool of sales associates, expand the current geographical area, and if the marginal increase in forecast sales revenues exceeds the additional salary and implementation costs, start hiring. Need a new manufacturing plant? Show that the construction costs can be recouped quickly and easily by the increase in revenues it will generate through new and more improved products, and the initiative is approved. However, real-life conditions are a lot more complicated. Your firm decides to go with a more automated 3D PDF software and Logistics Team Center environment, but multiple strategic paths exist. Which path do you choose? What are the options that you have? If you choose the wrong path, how do you get back on the right track? How do you value and prioritize the paths that exist? You are a venture capitalist firm with multiple business plans to consider. How do you value a start-up firm with no proven track record? How do you structure a mutually beneficial investment deal? What is the optimal timing to a second or third round of financing?

Real options are useful not only in valuing a firm, asset, or investment decision through its strategic business options but also as a strategic business tool in capital investment acquisition decisions. For instance, should the military invest millions in a new open architecture initiative, and if so, what are the values of the various strategies such an investment would enable, and how do we proceed? How does the military choose among several seemingly cashless, costly, and unprofitable information-technology infrastructure projects? Should it indulge its billions in a risky research and development initiative? The consequences of a wrong decision can be disastrous and lives could be at stake. In a traditional analysis, these questions cannot be answered with any certainty. In fact, some of the answers generated through the use of the traditional analysis are flawed because the model assumes a static, one-time decision-making process while the real options approach takes into consideration the strategic options certain projects create under uncertainty and a decision maker’s flexibility in exercising or abandoning these options at different points in time, when the level of uncertainty has decreased or has become known over time.

Real options analysis can be used to frame strategies to mitigate risk, value and find the optimal strategic pathway to pursue, and generate options to enhance the value of the project while managing risks. Sample options include the option to expand, contract, or abandon, or sequential compound options (phased stage-gate options, options to wait and defer investments, proof of concept stages, milestone development, and research and development initiatives). Some sample applications in the military include applications of real options to acquisitions, Spiral Development, and various organizational configurations, as well as the importance of how Integrated and Open Architectures become real options multipliers. Under OMB Circular A-76, comparisons using real options analysis could be applied to enhance outsourcing comparisons between the Government's Most Efficient Organization (MEO) and private sector alternatives. Real options can be used throughout JCIDS requirements generation and the Defense Acquisition System, for example, DOTMLPF vs. New Program/Service solution, Joint Integration, Analysis of Material Alternatives (AMA), Analysis of Alternatives (AoA), and Spiral Development. Many other applications exist in military decision analysis and portfolios.

Real Options: A Quick Peek Behind the Scenes

Real options analysis will be performed to determine the prospective value of the basic options over a multiyear period using KVA data as a platform. The strategic real options analysis is solved employing various methodologies, including the use of binomial lattices with a market-replicating portfolios approach, and backed up using a modified closed-form sequential compound option model. The value of a compound option is based on the value of another option. That is, the underlying variable for the compound option is another option, and the compound option can be either sequential in nature or simultaneous. Solving such a model requires programming capabilities. This subsection is meant as a quick peek into the math underlying a very basic closed-form compound option.[9] This section is only a preview of the detailed modeling techniques used in the current analysis and should not be assumed to be the final word.

For instance, we first start by solving for the critical value of *I,* an iterative component in the model using:

$$X_2 = Ie^{-q(T_2-t_1)}\Phi\left(\frac{\ln(I/X_1)+(r-q+\sigma^2/2)(T_2-t_1)}{\sigma\sqrt{(T_2-t_1)}}\right) - X_1 e^{-r(T_2-t_1)}\Phi\left(\frac{\ln(I/X_1)+(r-q-\sigma^2/2)(T_2-t_1)}{\sigma\sqrt{(T_2-t_1)}}\right)$$

Then, solve recursively for the value *I* above and input it into the model:

[9] We recommend reviewing *Real Options Analysis*: *Tools and Techniques,* Second Edition, by Johnathan Mun (2006) for more hands-on details and modeling techniques used in the analysis.

$$Compound\ Option = Se^{-qT_2}\Omega\left[\frac{\ln(S/X_1)+(r-q+\sigma^2/2)T_2}{\sigma\sqrt{T_2}};\ \frac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}};\sqrt{t_1/T_2}\right]$$

$$-X_1e^{-rT_2}\Omega\left[\frac{\ln(S/X_1)+(r-q+\sigma^2/2)T_2}{\sigma\sqrt{T_2}}-\sigma\sqrt{T_2};\ \frac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}}-\sigma\sqrt{t_1};\sqrt{t_1/T_2}\right]$$

$$-X_2e^{-rt_1}\Phi\left[\frac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}}-\sigma\sqrt{t_1}\right]$$

The model is then applied to a sequential problem where future phase options depend on previous phase options (e.g., Phase II depends on Phase I’s successful implementation).

Definitions of Variables

S	present value of future cash flows ($)
r	risk-free rate (%)
σ	volatility (%)
Φ	cumulative standard-normal
q	continuous dividend payout (%)
I	critical value solved recursively
Ω	cumulative bivariate-normal
X_1	strike for the underlying ($)
X_2	strike for the option on the option ($)
t_1	expiration date for the option on the option
T_2	expiration date for the underlying option

The preceding closed-form differential equation models are then verified using the risk-neutral market-replicating portfolio approach assuming a sequential compound option. In solving the market-replicating approach, we use the following functional forms (Mun, 2006):

- Hedge ratio *(h):*

$$h_{i-1} = \frac{C_{up} - C_{down}}{S_{up} - S_{down}}$$

- Debt load *(D):*

$$D_{i-1} = S_i(h_{i-1}) - C_i$$

- Call value *(C)* at node *i*:

$$C_i = S_i(h_i) - D_i e^{-rf(\delta t)}$$

- Risk-adjusted probability *(q):*

$q_i = \frac{S_{i-1} - S_{down}}{S_{up} - S_{down}}$ obtained assuming

$$S_{i-1} = q_i S_{up} + (1 - q_i) S_{down}$$

- This means that

$S_{i-1} = q_i S_{up} + S_{down} - q_i S_{down}$ and $q_i[S_{up} - S_{down}] = S_{i-1} - S_{down}$,

so we get $q_i = \frac{S_{i-1} - S_{down}}{S_{up} - S_{down}}$

Portfolio Optimization

In most decisions, there are variables over which leadership has control, such as how much to establish supply lines, modernize a ship, use network centricity to gather intelligence, and so on. Similarly, business leaders have options in what they charge for a product or how much to invest in a project or which projects they should choose in a portfolio when they are constrained by budgets or resources. These decisions could also include allocating financial resources, building or expanding facilities, managing inventories, and determining product-mix strategies. Such decisions might involve thousands or millions of potential alternatives. Considering and evaluating each of them would be impractical or even impossible. These controlled variables are called decision variables. Finding the optimal values for decision variables can make the difference between reaching an important goal and missing that goal. An optimization model can provide valuable assistance in incorporating relevant variables when analyzing decisions, and finding the best solutions for making decisions. Optimization models often provide insights that intuition alone cannot. An optimization model has three major elements: decision variables, constraints, and an objective. In short, the optimization methodology finds the best combination or permutation of decision variables (e.g., best way to deploy troops, build ships, which projects to execute) in every conceivable way such that the objective is maximized (e.g., strategic value, enemy assets destroyed, return on investment) or minimized (e.g., risk and costs) while still satisfying the constraints (e.g., time, budget, and resources).

Obtaining optimal values generally requires that you search in an iterative or ad hoc fashion. This search involves running one iteration for an initial set of values, analyzing the results, changing one or more values, rerunning the model, and repeating the process until you find a satisfactory solution. This process can be very tedious and time consuming even for small models, and often it is not clear how to adjust the values from one iteration to the next. A more rigorous method systematically enumerates all possible alternatives. This approach guarantees optimal solutions if the model is correctly specified. Suppose that an optimization model depends on only two decision variables. If each variable has 10 possible values, trying each combination requires 100 iterations (10^2 alternatives). If each iteration is very short (e.g., 2 seconds), then the entire process could be done in approximately three minutes of computer time. However, instead of two decision variables, consider six, then consider that trying all combinations requires 1,000,000 iterations (10^6 alternatives). It is easily possible for complete enumeration to take many years to carry out. Therefore, optimization has always been a fantasy until now; with the advent of sophisticated software and computing power, coupled with smart heuristics and algorithms, such analyses can be done within minutes.

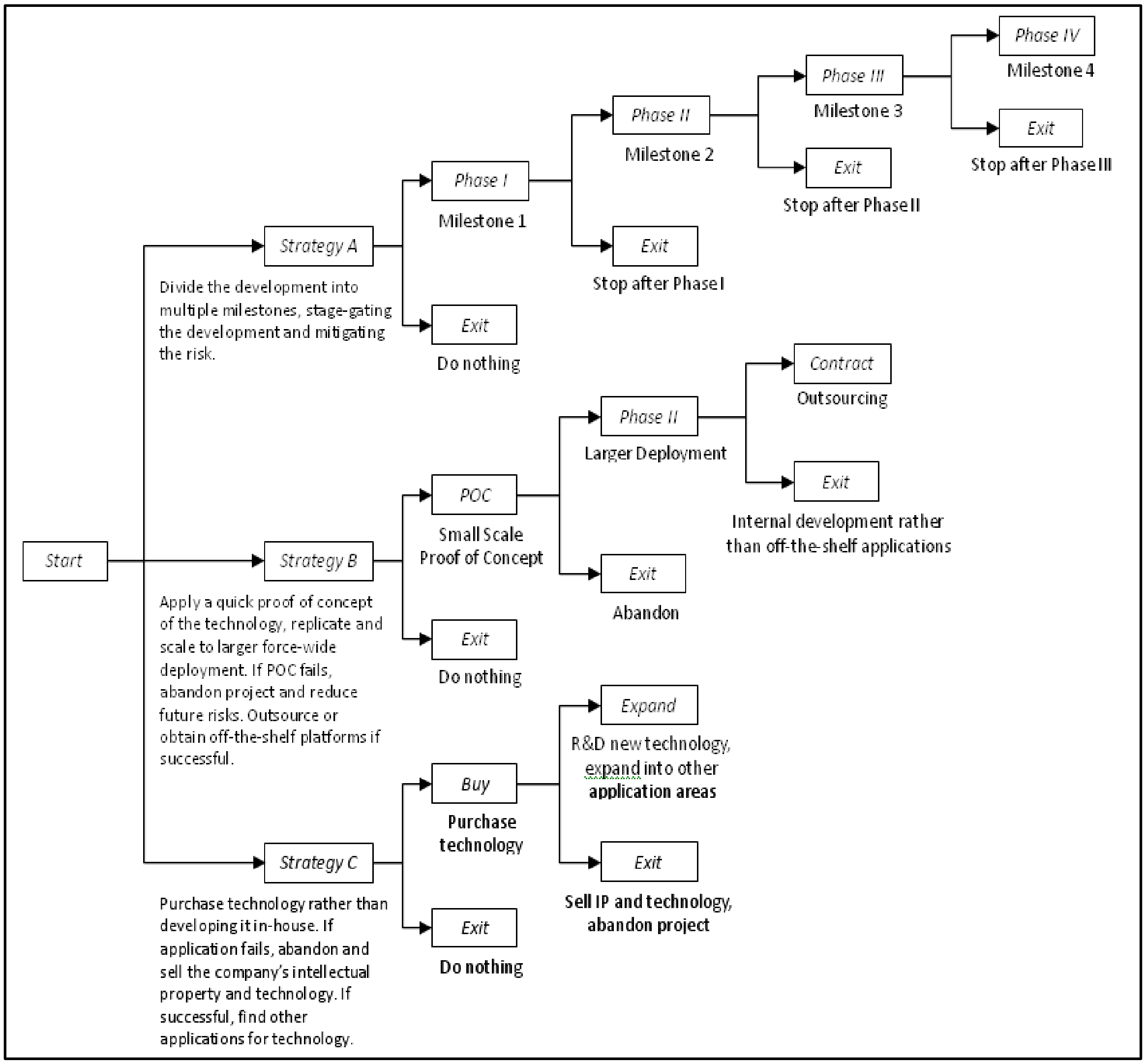

Figure B5. Example Real Options Framing

Figures B6, B7, and B8 illustrate a sample portfolio analysis where in the first case, there are 20 total projects to choose from (if all projects were executed, it would cost $10.2B) and where each project has its own returns on investment or benefits measure, cost, strategic ranking, comprehensive, and tactical and total military scores (these were obtained from field commanders through the Delphi method to elicit their thoughts about how strategic a particular project or initiative will be, and so forth). The constraints are full-time equivalence resources, budget, and strategic score. In other words, there are 20 projects or initiatives to choose from, where we want to select the top 10, subject to having enough money to pay for them and the people to do the work, and yet be the most strategic portfolio possible.[10] All the

[10] There are 2 x 10^{18} possible permutations for this problem, and if tested by hand, the calculation would take years to complete. Using *Risk Simulator*, the problem is solved in about 5 seconds, or several minutes if Monte Carlo simulation and real options are incorporated in the analysis.

while, Monte Carlo simulation, real options, and forecasting methodologies are applied in the optimization model (e.g., each project's values shown in Figure B6 are linked from its own large model with simulation and forecasting methodologies applied, and the best strategy for each project is chosen using real options analysis, or perhaps the projects shown are nested within one another; for instance, you cannot exercise Project 2 unless you execute Project 1, but you can only exercise Project 1 without having to do Project 2, and so forth). The results are shown in Figure B6.

Figure B7 shows the optimization process done in series, while relaxing some of the constraints. For instance, what would be the best portfolio and the strategic outcome if a budget of $3.8B was imposed? What if it was increased to $4.8B, $5.8B, and so forth? The efficient frontiers depicted in Figure B7 illustrate the best combination and permutation of projects in the optimal portfolio. Each point on the frontier is a portfolio of various combinations of projects that provides the best allocation possible given the requirements and constraints. Finally, Figure B8 shows the top 10 projects that were chosen and how the total budget is best and most optimally allocated to provide the best and most well-balanced portfolio.

Project Name	ENPV	Benefits	Cost	Strategy Ranking	Return to Rank Ratio	Profitability Index	Selection	Comprehensive Score	Tactical Score	FTE Resources	Military Score
Project 1	$458.00	$150.76	$1,732.44	1.20	381.67	1.09	0	8.10	2.31	1.20	1.98
Project 2	$1,954.00	$245.00	$859.00	9.80	199.39	1.29	1	1.27	4.83	2.50	1.76
Project 3	$1,599.00	$458.00	$1,845.00	9.70	164.85	1.25	0	9.88	4.75	3.60	2.77
Project 4	$2,251.00	$529.00	$1,645.00	4.50	500.22	1.32	0	8.83	1.61	4.50	2.07
Project 5	$849.00	$564.00	$458.00	10.90	77.89	2.23	0	5.02	6.25	5.50	2.94
Project 6	$758.00	$135.00	$52.00	7.40	102.43	3.60	1	3.64	5.79	9.20	3.26
Project 7	$2,845.00	$311.00	$758.00	19.80	143.69	1.41	1	5.27	6.47	12.50	4.04
Project 8	$1,235.00	$754.00	$115.00	7.50	164.67	7.56	1	9.80	7.16	5.30	3.63
Project 9	$1,945.00	$198.00	$125.00	10.80	180.09	2.58	1	5.68	2.39	6.30	2.16
Project 10	$2,250.00	$785.00	$458.00	8.50	264.71	2.71	1	8.29	4.41	4.50	2.67
Project 11	$549.00	$35.00	$45.00	4.80	114.38	1.78	0	7.52	4.65	4.90	2.75
Project 12	$525.00	$75.00	$105.00	5.90	88.98	1.71	0	5.54	5.09	5.20	2.69
Project 13	$516.00	$451.00	$48.00	2.80	184.29	10.40	0	2.51	2.17	4.60	1.66
Project 14	$499.00	$458.00	$351.00	9.40	53.09	2.30	1	9.41	9.49	9.90	4.85
Project 15	$859.00	$125.00	$421.00	6.50	132.15	1.30	1	6.91	9.62	7.20	4.25
Project 16	$884.00	$458.00	$124.00	3.90	226.67	4.69	1	7.06	9.98	7.50	4.46
Project 17	$956.00	$124.00	$521.00	15.40	62.08	1.24	1	1.25	2.50	8.60	2.07
Project 18	$854.00	$164.00	$512.00	21.00	40.67	1.32	0	3.09	2.90	4.30	1.70
Project 19	$195.00	$45.00	$5.00	1.20	162.50	10.00	0	5.25	1.22	4.10	1.86
Project 20	$210.00	$85.00	$21.00	1.00	210.00	5.05	0	2.01	4.06	5.20	2.50
Total	$14,185.00		$3,784.00	99.00			10	**58.58**	**62.64**	73.50	**33.15**
Profit/Rank	$143.28										
Profit*Score	$470,235.60	Maximize	< =$3800	< =100			x<=10			<=80	

Figure B6. Portfolio Optimization and Allocation

Budget	*Military Score*	*Tactical Score*	*Comprehensive Score*	*Allowed Projects*	*ROI-RANK Objective*
$3,800.00	*33.15*	*62.64*	*58.58*	*10*	*$470,235.60*
$4,800.00	*36.33*	*68.85*	*66.86*	*11*	*$521,645.92*
$5,800.00	*38.40*	*70.46*	*75.69*	*12*	*$623,557.79*
$6,800.00	*39.94*	*72.14*	*82.31*	*13*	*$659,947.99*
$7,800.00	*39.76*	*70.05*	*86.54*	*14*	*$676,279.81*

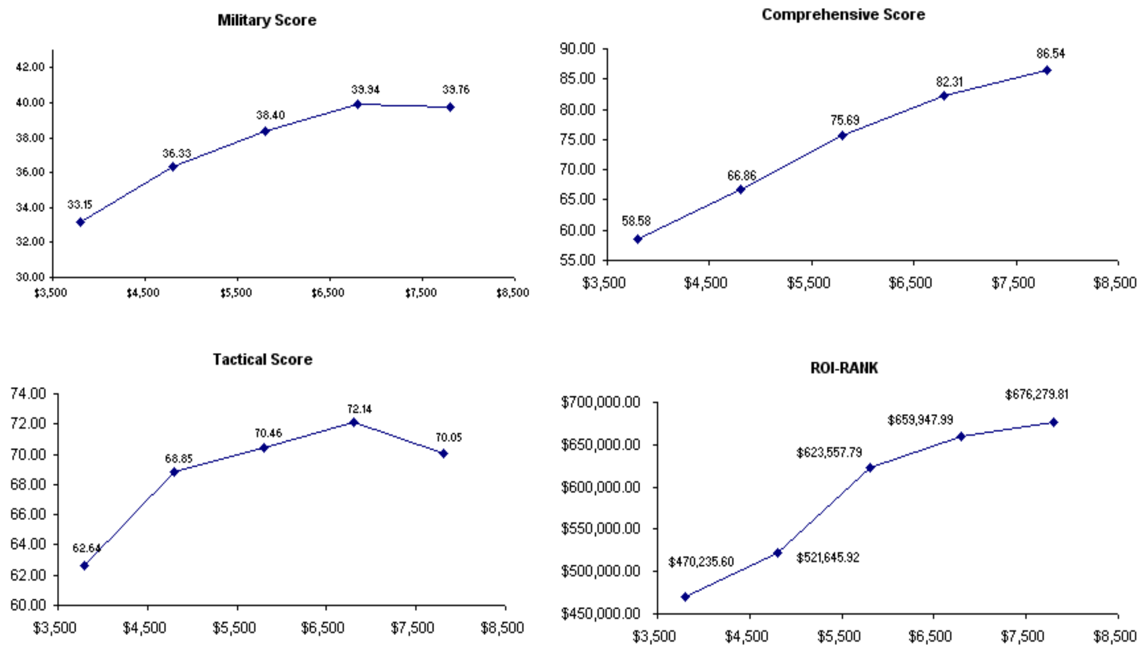

Figure B7. Efficient Frontiers of Portfolios

ASSET ALLOCATION OPTIMIZATION MODEL

Asset Class Description	Annualized Returns	Volatility Risk	Allocation Weights	Required Minimum Allocation	Required Maximum Allocation	Return to Risk Ratio	Returns Ranking (Hi-Lo)	Risk Ranking (Lo-Hi)	Return to Risk Ranking (Hi-Lo)	Allocation Ranking (Hi-Lo)
Selected Project 1	10.50%	12.38%	11.10%	5.00%	35.00%	0.8483	9	2	7	4
Selected Project 2	11.12%	16.36%	6.74%	5.00%	35.00%	0.6799	7	8	10	10
Selected Project 3	11.77%	15.81%	7.63%	5.00%	35.00%	0.7445	6	7	9	9
Selected Project 4	10.77%	12.33%	11.49%	5.00%	35.00%	0.8738	8	1	5	3
Selected Project 5	13.49%	13.35%	12.26%	5.00%	35.00%	1.0102	5	4	2	2
Selected Project 6	14.24%	14.53%	10.94%	5.00%	35.00%	0.9800	3	6	3	5
Selected Project 7	15.60%	14.30%	12.36%	5.00%	35.00%	1.0908	1	5	1	1
Selected Project 8	14.95%	16.64%	8.75%	5.00%	35.00%	0.8983	2	10	4	7
Selected Project 9	14.15%	16.56%	8.36%	5.00%	35.00%	0.8545	4	9	6	8
Selected Project 10	10.08%	12.55%	10.37%	5.00%	35.00%	0.8027	10	3	8	6
Portfolio Total	*12.7270%*	*4.54%*	*100.00%*							
Return to Risk Ratio	*2.8021*									

Figure B8. Portfolio Optimization (Continuous Allocation of Funds)

Integrated Risk Management Framework

We are now able to put all the pieces together into an *integrated risk management framework* and see how these different techniques are related in a risk analysis and risk management context. This framework comprises eight distinct phases of a successful and comprehensive risk analysis implementation, going from a qualitative management screening process to creating clear and concise reports for management. The process was developed by the author (Mun) based on previous successful implementations of risk analysis, forecasting, real options, KVA cash-flow estimates, valuation, and optimization projects both in the consulting arena and in industry-specific problems. These phases can be performed either in isolation or together in sequence for a more robust integrated analysis.

Figure B9 shows the integrated risk management process up close. We can segregate the process into the following eight simple steps:

1. Qualitative management screening
2. Time-series and regression forecasting
3. Base case KVA and net present value analysis
4. Monte Carlo simulation
5. Real options problem framing
6. Real options modeling and analysis
7. Portfolio and resource optimization
8. Reporting and update analysis

1. Qualitative Management Screening

Qualitative management screening is the first step in any integrated risk management process. Decision makers have to decide which projects, assets, initiatives, or strategies are viable for further analysis, in accordance with the organization's mission, vision, goal, or overall business strategy. The organization's mission, vision, goal, or overall business strategy may include strategies and tactics, and competitive advantage, technical, acquisition, growth, synergistic, or global threat issues. That is, the initial list of projects should be qualified in terms of meeting the leadership's agenda. Often the most valuable insight is created as leaders frame the complete problem to be resolved. This is where the various risks to the organization are identified and fleshed out.

2. Time-Series and Regression Forecasting

The future is then forecasted using time-series analysis, stochastic forecasting, or multivariate regression analysis if historical or comparable data exist. Otherwise, other qualitative forecasting methods may be used (subjective guesses, growth rate assumptions, expert opinions, Delphi method, and so forth).[11]

3. Base Case KVA and Net Present Value Analysis

For each project that passes the initial qualitative screens, a KVA-based discounted cash flow model is created. This model serves as the base case analysis where a net present value and ROI are calculated for each project, using the forecasted values in the previous step. This step also applies if only a single project is under evaluation. This net present value is calculated with the traditional approach of using the forecast revenues and costs, and discounting the net of these revenues and costs at an appropriate risk-adjusted rate. The ROI and other financial metrics are generated here.

4. Monte Carlo Simulation[12]

Because the static discounted cash flow produces only a single-point estimate result, there is oftentimes little confidence in its accuracy given that future events that affect forecast cash flows are highly uncertain. To better estimate the actual value of a particular project, Monte Carlo simulation should be employed next. Usually, a sensitivity analysis is first performed on the discounted cash flow model; that is, setting the net present value or ROI as the resulting variable, we can change each of its precedent variables and note the change in the resulting variable. Precedent variables include revenues, costs, tax rates, discount rates, capital expenditures, depreciation, and so forth, which ultimately flow through the model to affect the net present value or ROI figure. By tracing back all these precedent variables, we can change each one by a preset amount and see the effect on the resulting net present value. A graphical representation can then be created in Risk Simulator, which is often called a tornado chart because of its shape, where the most sensitive precedent variables are listed first, in descending order of magnitude. Armed with this information, the analyst can then decide which key variables are highly uncertain in the future and which are deterministic. The uncertain key variables that drive the net present value and, hence, the decision are called critical success drivers. These critical success drivers are prime candidates for Monte Carlo simulation. Because some of these critical success drivers may be correlated, a

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[11] See Chapters 8 and 9 of *Modeling Risk* (Wiley, 2006) by Dr. Johnathan Mun for details on forecasting and using the author's *Risk Simulator* software to run time-series analysis, extrapolation, stochastic process, ARIMA, and regression forecasts.
[12] See Chapters 4 and 5 of *Modeling Risk* (Wiley, 2006) by Dr. Johnathan Mun for details on running Monte Carlo simulation using the author's *Risk Simulator* software.

correlated and multidimensional Monte Carlo simulation may be required. Typically, these correlations can be obtained through historical data. Running correlated simulations provides a much closer approximation to the variables' real-life behaviors.

5. Real Options Problem Framing[13]

The question now is that after quantifying risks in the previous step, what next? The risk information obtained somehow needs to be converted into *actionable intelligence*. Just because risk has been quantified to be such and such using Monte Carlo simulation, so what and what do we do about it? The answer is to use real options analysis to hedge these risks, to value these risks, and to position yourself to take advantage of the risks. The first step in real options is to generate a strategic map through the process of framing the problem. Based on the overall problem identification occurring during the initial qualitative management screening process, certain strategic optionalities would have become apparent for each particular project. The strategic optionalities may include, among other things, the option to expand, contract, abandon, switch, choose, and so forth. Based on the identification of strategic optionalities that exist for each project or at each stage of the project, the analyst can then choose from a list of options to analyze in more detail. Real options are added to the projects to hedge downside risks and to take advantage of upside swings.

6. Real Options Modeling and Analysis

Through the use of Monte Carlo simulation, the resulting stochastic discounted cash flow model will have a distribution of values. Thus, simulation models, analyzes, and quantifies the various risks and uncertainties of each project. The result is a distribution of the NPVs and the project's volatility. In real options, we assume that the underlying variable is the future profitability of the project, which is the future cash flow series. An implied volatility of the future free cash flow or underlying variable can be calculated through the results of a Monte Carlo simulation previously performed. Usually, the volatility is measured as the standard deviation of the logarithmic returns on the free cash flow stream. In addition, the present value of future cash flows for the base case discounted cash flow model is used as the initial underlying asset value in real options modeling. Using these inputs, real options analysis is performed to obtain the projects' strategic option values.

[13] See *Real Options Analysis: Tools and Techniques*, Second Edition (Wiley, 2005) by Dr. Johnathan Mun for more technical details on framing and solving real options problems.

7. Portfolio and Resource Optimization[14]

Portfolio optimization is an optional step in the analysis. If the analysis is done on multiple projects, decision makers should view the results as a portfolio of rolled-up projects because the projects are in most cases correlated with one another, and viewing them individually will not present the true picture. As organizations do not only have single projects, portfolio optimization is crucial. Given that certain projects are related to others, there are opportunities for hedging and diversifying risks through a portfolio. Because firms have limited budgets and time and resource constraints, while at the same time have requirements for certain overall levels of returns, risk tolerances, and so forth, portfolio optimization takes into account all these to create an optimal portfolio mix. The analysis will provide the optimal allocation of investments across multiple projects.

8. Reporting and Update Analysis

The analysis is not complete until reports can be generated. Not only are results presented, but the process should also be shown. Clear, concise, and precise explanations transform a difficult black-box set of analytics into transparent steps. Decision makers will never accept results coming from black boxes if they do not understand where the assumptions or data originate and what types of mathematical or analytical massaging takes place. Risk analysis assumes that the future is uncertain and that decision makers have the right to make midcourse corrections when these uncertainties become resolved or risks become known; the analysis is usually done ahead of time and thus ahead of such uncertainty and risks. Therefore, when these risks become known over the passage of time, actions, and events, the analysis should be revisited to incorporate the decisions made or revising any input assumptions. Sometimes, for long-horizon projects, several iterations of the real options analysis should be performed, where future iterations are updated with the latest data and assumptions. Understanding the steps required to undertake an integrated risk management analysis is important because it provides insight not only into the methodology itself but also into how it evolves from traditional analyses, showing where the traditional approach ends and where the new analytics start.

[14] See Chapters 10 and 11 of *Modeling Risk* (Wiley, 2006) by Dr. Johnathan Mun for details on using *Risk Simulator* to perform portfolio optimization.

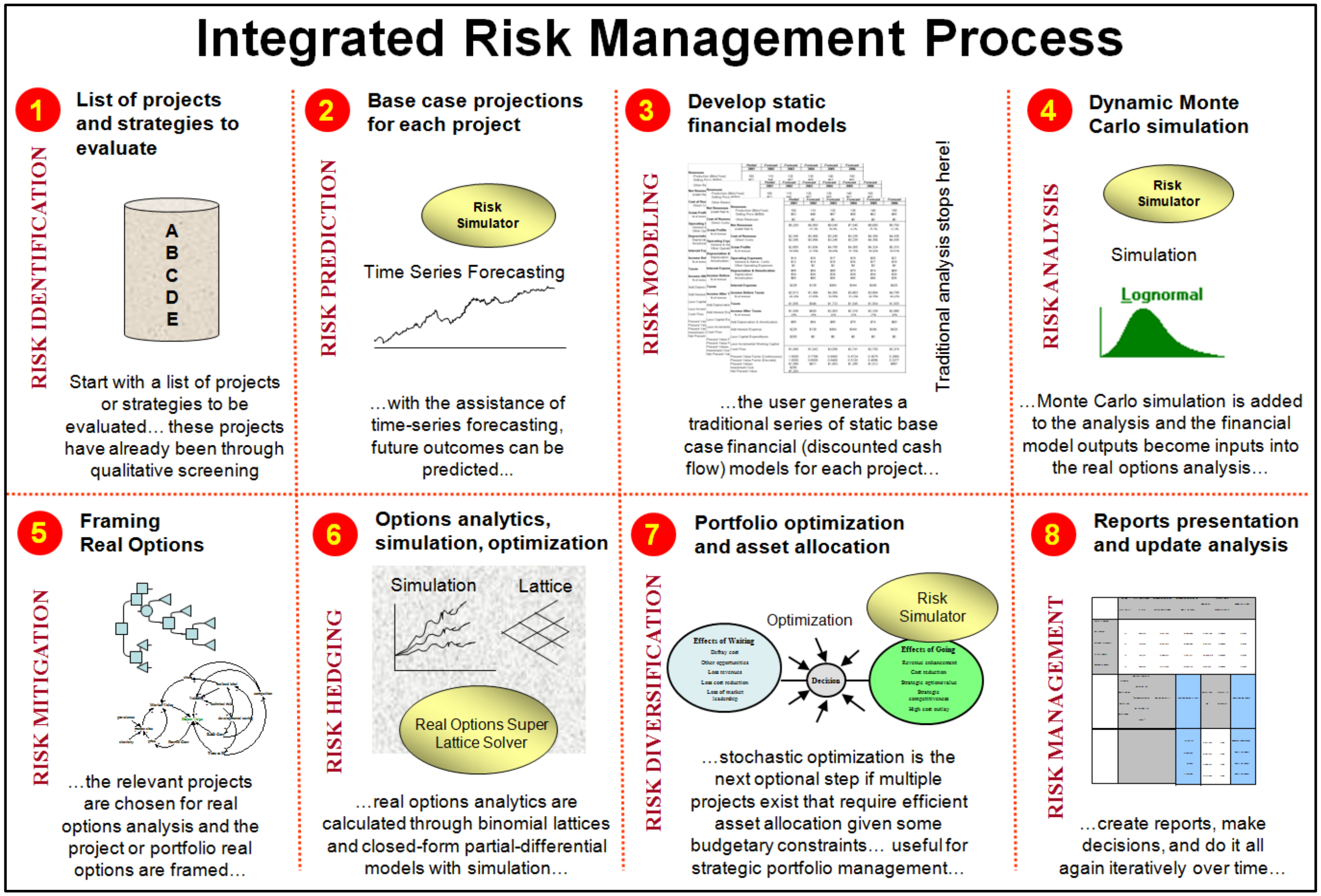

Figure B9. Integrated Risk Management Process

Conclusion

Hopefully it has now become evident that the DOD leadership can take advantage of more advanced analytical procedures for making strategic investment decisions and when managing portfolios of projects. In the past, due to the lack of technological maturity, this would have been extremely difficult, and, hence, businesses and the government had to resort to experience and managing by gut feel. Nowadays with the assistance of technology and more mature methodologies, there is every reason to take the analysis a step further. Corporations such as 3M, Airbus, AT&T, Boeing, BP, Chevron, Johnson & Johnson, Motorola, and many others have already been successfully using these techniques for years, and the military can follow suit. The relevant software applications, books, case studies, and public seminars have been created, and case studies have already been developed for the U.S. Navy.[15] The only barrier to implementation, simply put, is the lack of exposure to the potential benefits of the methods. Many in the military have not seen or even heard of these new concepts. This primer, if it is successful, serves to reveal the potential benefits of these analytical techniques and tools that can complement what leadership is currently doing. In order to be ready for the challenges of the 21st century, and to create a highly effective and flexible military force, strategic real options, KVA, and risk analysis are available to aid leadership with critical decision making. Real options and KVA are tools that will help ensure maximum strategic flexibility and analysis of alternatives where risks must be considered.

[15] See www.realoptionsvaluation.com (Download site) for more details on the software applications *Risk Simulator* and *Real Options SLS,* as well as sample case studies, videos, sample models, and training seminars (e.g., the 4-day Certified Risk Analyst public seminars cover all the methodologies outlined in this primer and more).

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