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Naval Ship Maintenance: An Analysis of the Dutch Shipbuilding Industry Using the Knowledge Value Added, Systems Dynamics, and Integrated Risk Management Methodologies

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Naval Ship Maintenance: An Analysis of the Dutch Shipbuilding Industry Using the Knowledge Value Added, Systems Dynamics, and Integrated Risk Management Methodologies

10 October 2012

by

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Abstract

Initiatives to reduce the cost of ship maintenance have not yet realized the normal cost-reduction learning curve improvements. One explanation is the lack of recommended technologies. Damen, a Dutch shipbuilding and service firm, has incorporated similar technologies and is developing others to improve its operations. The research team collected data on Dutch ship maintenance operations and used them to build three types of computer simulation models of ship maintenance and technology adoption. The results were analyzed and compared with previously developed modeling results of U.S. Navy ship maintenance and technology adoption. Adopting 3D PDF alone improves ROI significantly more than adopting a logistics package alone and adding both technologies improves ROI more than adding either technology alone. Adoption of the technologies would provide cost benefits far in excess of not using the technologies and there were marginal benefits in sequentially implementing the technologies over immediately implementing them. There are a number of issues in comparing the results with previous research but the potential benefits of using the technologies are very high in both cases. Implications for acquisition practice include the need for careful analysis and selection from among a variety of available information technologies and the recommendation for a phased development and implementation approach to manage uncertainty.

Keywords: Technology adoption, ship maintenance, Laser scanning technology, Collaborative product lifecycle management

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Executive Summary

There have been a series of initiatives designed to reduce the cost of ship maintenance. SHIPMAIN, and its derivatives, was one of the initiatives designed to improve ship maintenance performance within the Navy by standardizing processes in order to take advantage of learning-curve cost savings. However, these process improvement initiatives have not yet realized the normal cost-reduction learning curve improvements for common maintenance items for a series of common platform ships. One explanation is that the initial instantiation of SHIPMAIN did not include two recommended technologies, 3-dimensional laser scanning technology (3D LST) and collaborative product lifecycle management (CPLM), that were deemed necessary by the creator of SHIPMAIN for ensuring the success of the new standardized approach (i.e., normal learning curve cost savings).

Damen, a large Dutch shipbuilding and service firm has incorporated similar technologies and is developing others to improve its operations. In addition, the Royal Dutch Navy performs all of its own ship maintenance in a single yard and operation, and, we extrapolated and compared the potential benefits of similar technologies with similar projections for the U.S. Navy ship maintenance processes. These organizations provide a source of relatively reliable data on operations that are comparable to those performed by the U.S. Navy. One variation on the 3D LST technology was the use of 3D PDF by the Damen company. The 3D PDF technology was roughly comparable to the potential use of 3D LST and provided a baseline approximation for the use of 3D LST in projecting the future value of the technology.

This study compared the Dutch experience with projections for the use of the two technologies in the U.S. Navy. Because the technologies have not been fully implemented in the Dutch shipbuilding and ship maintenance venue, we extrapolated from the partial implementation of CPLM and 3D PDF in order to compare potential projections of possible improvements in both the Dutch and U.S. cases.

The current work addresses the following questions:

How are the Dutch using and preparing to adopt advanced technologies, such as 3D LST and CPLM, in shipbuilding and maintenance?

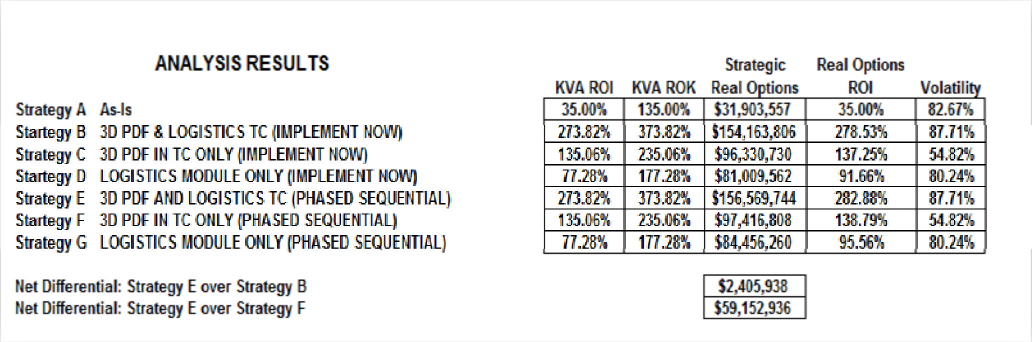
What are the potential changes in ROIs provided by the adoption of these advanced technologies?

How do those potential returns compare with projected estimates of returns on technology adoption of 3D LST and CPLM in the U.S. Navy?

The research team collected data on Dutch ship maintenance operations and used them to build three types of computer simulation models of ship maintenance and technology adoption. The approach included use of the knowledge value added (KVA) models of return on technology investments in those operations, system dynamics models (based on the KVA preliminary ROI results) of ship maintenance operations, and integrated risk management (IRM) models of implementation plans for the technology adoption. The results were then analyzed and compared with previously developed modeling results of U.S. Navy ship maintenance and technology adoption.

The linear ROI projections from adopting various iterations of the partial CPLM tool (i.e., only the logistics package) and the 3D PDF tool in the Dutch context demonstrated the advantages of adopting both technologies over either technology alone, compared to a baseline without either technology. Adopting 3D PDF alone improves ROI significantly more than adopting a logistics package alone (100% improvement > 46% improvement) and adding both technologies improves ROI more than adding either technology alone (239% improvement > 42% improvement or 100% improvement), suggesting that there may be synergy between the technologies. This is also supported by the 139% improvement gained by adding logistics if 3D PDF is already in place. These results were then used to forecast the benefits of various adoption options for the tools using the IRM methodology.

The results of the IRM analysis provided forecasts of the benefits of various options for implementing the technologies separately or in combination. The results (shown in the following figure) indicated that adoption of the technologies would provide cost benefits far in excess of not using the technologies. In addition, the results indicated that there were marginal benefits in sequentially implementing the technologies over immediately implementing them. Given the long cycle for organizations to benefit from technology adoption, it might be better to adopt the technologies immediately.



ANALYSIS RESULTS

		KVA ROI	KVA ROK	Strategic Real Options	Real Options ROI	Volatility
Strategy A	As-Is	35.00%	135.00%	$31,903,557	35.00%	82.67%
Startegy B	3D PDF & LOGISTICS TC (IMPLEMENT NOW)	273.82%	373.82%	$154,163,806	278.53%	87.71%
Strategy C	3D PDF IN TC ONLY (IMPLEMENT NOW)	135.06%	235.06%	$96,330,730	137.25%	54.82%
Startegy D	LOGISTICS MODULE ONLY (IMPLEMENT NOW)	77.28%	177.28%	$81,009,562	91.66%	80.24%
Strategy E	3D PDF AND LOGISTICS TC (PHASED SEQUENTIAL)	273.82%	373.82%	$156,569,744	282.88%	87.71%
Startegy F	3D PDF IN TC ONLY (PHASED SEQUENTIAL)	135.06%	235.06%	$97,416,808	138.79%	54.82%
Strategy G	LOGISTICS MODULE ONLY (PHASED SEQUENTIAL)	77.28%	177.28%	$84,456,260	95.56%	80.24%

Net Differential: Strategy E over Strategy B	$2,405,938
Net Differential: Strategy E over Strategy F	$59,152,936

Comparing these results with U.S. Navy results offers some partially confirming evidence for the prior research that projected the benefits of adopting CPLM and 3D LST technologies for ship maintenance. There are a number of issues in making these comparisons that must be noted given the differences in the size of the two countries' ship maintenance operations and in the extent of implementation of the two types of technologies. However, the comparisons have validity when these issues are accounted for, and the potential benefits of using the technologies are very high in both cases.

The scenarios have some similarities. All overall returns on investment are positive and large. This supports the adoption of advanced technologies such as 3D LST, 3D PDF models, and CPLM to improve the efficiency of resource use. The scenarios also have potentially significant differences. The preparation for maintenance phases of the U.S. scenario has a much larger technology-adopted return on investment than the maintenance implementation phases of the U.S. scenario or the Dutch scenario (2,019% >> 201% or 274%). Several factors could explain this difference. A real options approach was applied to investigate the impacts of technology selection and implementation strategies on project value. The adoption of 3D PDF models and a logistics management package within a CPLM environment was found to provide the greatest value.

Implications for acquisition practice include the need for careful analysis and selection from among a variety of available information technologies and the recommendation for a phased development and implementation approach to manage uncertainty.

I. Introduction

The current cost-constrained environment within the federal government and DoD requires a defensible approach to cost reductions without compromising the capability of core defense processes and platforms. Due to this environment, defense leaders today must maintain and modernize the U.S. armed forces to retain technological superiority while simultaneously balancing defense budget cost constraints and extensive military operational commitments. At the same time, defense leaders must navigate a complex information technology (IT) acquisition process. Maintenance programs play a critical role in meeting these DoD objectives. One such core process that is central to U.S. naval operations is the ship maintenance process. This process alone accounts for billions of dollars in the U.S. Navy's annual budget. There have been a series of initiatives designed to reduce the cost of this core process, including ship maintenance. SHIPMAIN, and its derivatives, was one of the initiatives designed to improve ship maintenance performance within the Navy by standardizing processes in order to take advantage of learning curve cost savings. Figure 1 provides a notional picture of this phenomenon.

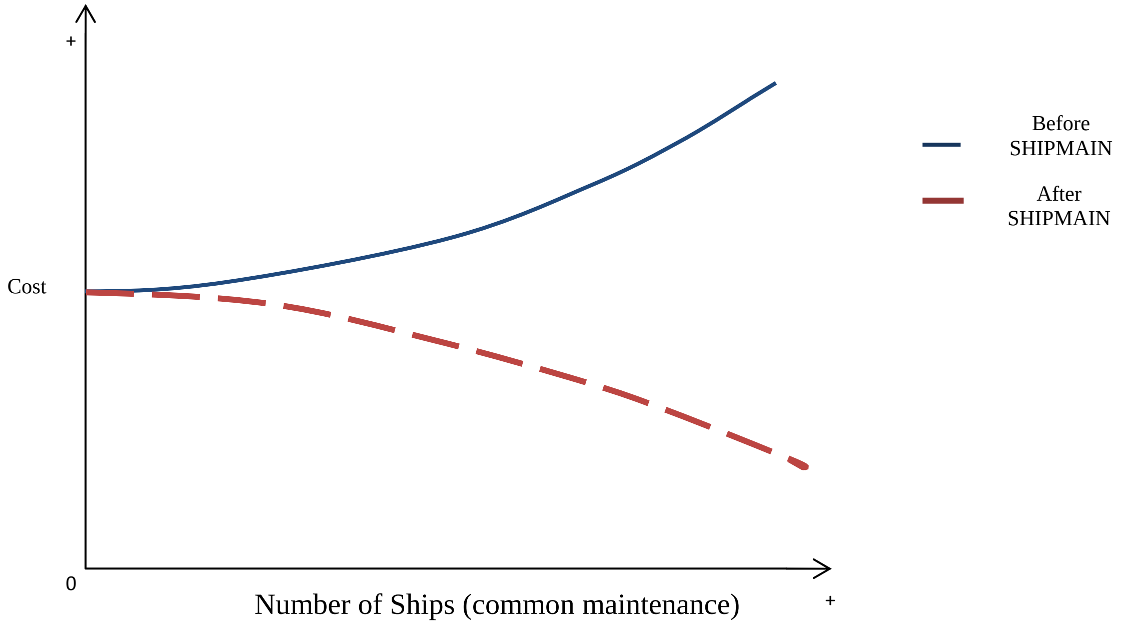


Figure 1. Ship Maintenance Learning Curve

However, these process improvement initiatives have not yet realized the normal cost-reduction learning curve improvements for common maintenance items for a series of common platform ships. One explanation is that the initial instantiation of SHIPMAIN did not include two recommended technologies, 3-dimensional laser scanning technology (3D LST) and collaborative product lifecycle management (CPLM), that were deemed necessary by the creator of SHIPMAIN for ensuring the success of the new standardized approach (i.e., normal learning curve cost savings). Previous research (Ford, Housel, & Mun, 2011) indicates that adding these technologies may help SHIPMAIN, or its derivatives, to capture the potential saving. But the technologies have not been implemented to date in the ship maintenance processes.

However, Damen, a large shipbuilding and service firm has incorporated similar technologies and is developing others to improve its operations. In addition, the Royal Dutch Navy performs all of its own ship maintenance in a single yard and operation. In the current study the potential benefits of similar technologies are extrapolated and compared with similar projections for U.S. Navy ship maintenance processes. These organizations provide a source of relatively reliable data on operations that are comparable to those performed by the U.S. Navy.

A. Problem Description

Previous research on the potential use of 3D LST and CPLM technology in U.S. Navy ship maintenance (e.g., Komoroski, 2005; Ford, Housel, & Mun, 2011) estimated the impacts on processes due to technology adoption. Changes such as reengineering ship maintenance processes, the sizes of reductions in cycle times, and workforce requirements are examples of model portions that required modelers to make assumptions about the potential impacts of these technologies in modeling projected results. While the previous work has provided defensible estimates of potential improvements (in returns on investment, ROI) and cost savings, the validity and usefulness of these models has been limited by the lack of comparative data on ship maintenance processes and technology investments, and of their potential impacts on performance. Therefore, the acquisition of data on Dutch naval fleet maintenance processes and comparison of those data with previous U.S. Navy results was a critical next step in improving U.S. naval technology acquisition decision-making, in particular with regard to ship maintenance.

To be valuable, the data source or sources for this work had to have several critical similarities with U.S. naval ship maintenance processes. The data source had to consider technological innovation and the adoption of advanced technologies to be an important part of its naval maintenance acquisition strategy. The data source or sources had to be large enough to support continuous ship maintenance operations because the intermittent stopping and restarting of operations would not be consistent with important assumptions of the modeling approach. Finally, the data source had to be accessible, willing to share the data, and willing to allow us to obtain the new data required for our modeling approach. These and other criteria limited the potential pool of sources to nations or large industrial ship maintenance organizations that were on good terms with the United States, advanced enough in their operations to compare with those of the U.S. Navy, progressive enough in their strategies to include continuous technology adoption, and willing to share data and information that is often considered essential for national security or competitive advantage. Damen Industries and the Royal Dutch Navy (RDN) met most of these criteria and were willing to meet our requirements for data acquisition and sharing.

The current work addresses the following questions:

- How are the Dutch using and preparing to adopt advanced technologies, such as 3D LST and CPLM, in shipbuilding and maintenance?
- What are the potential changes in ROIs provided by the adoption of these advanced technologies?
- How do those potential returns compare with projected estimates of returns on technology adoption of 3D LST and CPLM in the U.S. Navy?

B. Research Methodology and Background

The traditional ROI equation is typically expressed as (Revenue – Investment) / Investment, which represents the productivity ratio of output (i.e., Revenue in ROI ÷ Input or Investment Cost in ROI). Accomplishing this analysis in a nonprofit environment presents challenges because there is no actual revenue generated. Cost savings from reductions in manpower requirements (i.e., time allocated to employee workload for various tasks) is available to provide the impact on the denominator of the ship maintenance efforts. However, the knowledge value added (KVA) methodology also allows for generation of a quantifiable surrogate for revenue in the form of common units of output described in terms of units of learning time.[1] Specifically, the KVA methodology allowed the study team to quantify the knowledge embedded in the new processes to use in generating common units of output estimates.

The KVA analysis provided the basic ROI estimates critical in forecasting the future value of various automation options within an optimized portfolio over time using the integrated risk management (IRM) framework and supporting toolset.

The research team collected data on Dutch ship operations as described in the Data Collection section and used it to build three types of computer simulation models of ship maintenance and technology adoption: knowledge value added (KVA) models of return on technology investments in those operations, system dynamics models (based on the KVA preliminary ROI results) of ship maintenance operations, and integrated risk management models of implementation plans for technology adoption. The results were then analyzed and compared with previously developed modeling results of U.S. Navy ship maintenance and technology adoption. In what follows, we review the three approaches to projecting the potential cost benefits of adopting the technologies, beginning with a general review of the KVA, SD, and IRM approaches. This is followed by the projected results from applying these approaches to assess the impacts of the

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[1] KVA can provide other means for describing outputs in common units, such as lines of code (controlling for complexity per line of code) and process instructions (controlling for complexity per instruction), as well as other means.

two technologies. A comparison of the Dutch and U.S. naval maintenance results is provided followed by the results of the IRM forecasts.

Knowledge value added (KVA) measures the value provided by human capital and IT assets by an organization, process, or function at the subprocess level (Figure 2). 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 the actual cost and revenue of a product or service to be calculated.

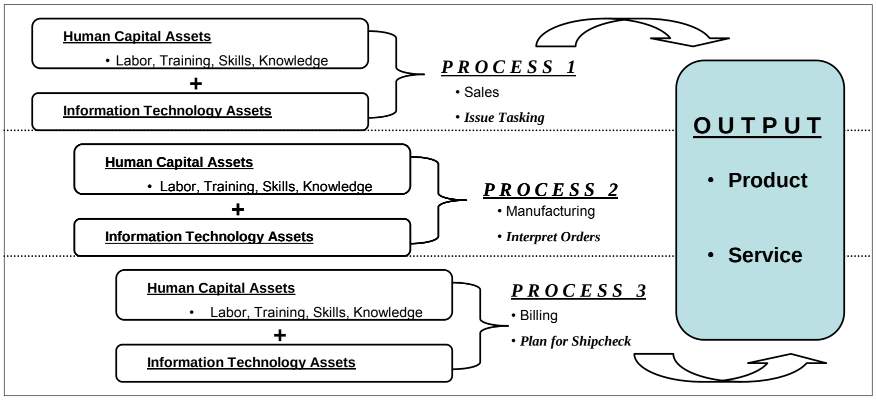

Figure 2. Measuring Output

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 3. 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). While 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 IT investments do not improve the ROK value of a given process, steps must be taken to improve that process's function and performance.

Table 1. KVA Metrics

Metric	Description	Type	Calculation
Return on Knowledge (ROK)	Basic productivity, cash-flow ratio	Subcorporate, process-level performance ratio	$\frac{\text{(Outputs-Benefits in Common Units)}}{\text{Cost to Produce Output}}$
Return on Investment (ROI)	Same as ROI at the sub-corporate, process level	Traditional investment finance ratio	$\frac{\text{(Revenue-Investment Cost)}}{\text{Investment cost}}$

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 Dutch 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, 3D and LST in ship maintenance core processes in the U.S. Navy yards.

C. System Dynamics

The system dynamics methodology applies a control theory perspective to the design and management of complex human systems. System dynamics combines servo-mechanism thinking with computer simulation to create insights about the development and operation of these systems. It is one of several established and successful approaches to systems analysis and design (Flood & Jackson, 1991; Lane & Jackson, 1995; Jackson, 2003). Forrester (1961) develops the methodology's philosophy, and Sterman (2000) specifies the modeling process with examples and describes numerous applications. System dynamics is used to build causal-based (vs. correlation-based) models that reflect the components and interactions that drive behavior and performance. The methodology has been used extensively to explain, design, manage, and, thereby, improve the performance of many types of systems, including development projects. The system dynamics perspective focuses on how the internal structure of a system impacts system and managerial behavior and, thereby, performance over time. The approach is unique in its integrated use of stocks and flows, causal feedback, and time delays to model and explain processes, resources, information, and management policies. Stocks represent accumulations or backlogs of work, people, information, or other portions of the system that change over time. Flows represent the movement of those commodities into, between, and out of stocks. The methodology's ability to model many diverse system components (e.g., work, people, money, value), processes (e.g., design, technology development, production, operations, quality assurance), and managerial decision-making and actions (e.g., forecasting, resource allocation) makes system dynamics useful for modeling and investigating military operations, the design of materiel, and acquisition.

When applied to acquisition programs, system dynamics has focused on how performance evolves in response to interactions among development strategy (e.g., evolutionary development versus traditional), managerial decision-making (e.g., scope developed in specific blocks), and development processes (e.g., concurrence). System dynamics is appropriate for modeling acquisition because of its ability to explicitly model critical aspects of development projects. System dynamics models of development projects are purposefully simple relative to actual practice to expose the relationships between causal structures and the behavior and performance that they create. Therefore, although many processes and features inherent in system design and used by participants interact to determine performance, only those that describe features related to the topic of study are included in system dynamics models.

System dynamics has been successfully applied to a variety of development and project management issues, including rework (Cooper, 1993a, 1993b,1993c; Cooper & Mullen, 1993), the prediction and discovery of failures in project fast-track implementation (Ford & Sterman, 2003b), poor schedule performance (Abdel-Hamid, 1988), tipping point structures in projects (Taylor & Ford, 2008, 2006), contingency management (Ford, 2002), resource allocation (Joglekar & Ford, 2005; Lee, Ford, & Joglekar, 2007), and the impacts of changes (Rodriguez & Williams, 1998; Cooper, 1980) and concealing rework requirements (Ford & Sterman, 2003a) on project performance. See Lyneis and Ford (2007) for a review of the application of system dynamics to projects and project management.

System dynamics has also been applied to military systems, including planning and strategy (Melhuish, Pioch, & Seidel, 2009; Bakken & Vamraak, 2003; Duczynski, 2000; McLucas, Lyell, & Rose, 2006), workforce management (Bell & Liphard, 1978), technology (Bakken, 2004), command and control (Bakken & Gilljam, 2003; Bakken, Gilljam, & Haerem, 2004), operations (Bakken, Ruud, & Johannessen, 2004; Coyle & Gardiner, 1991), logistics (Watts & Wolstenholme, 1990), acquisition (Ford, Housel, & Dillard, 2010; Ford, Housel, & Mun, 2011; Ford & Dillard 2009a, 2009b, 2008; Bartolomei, 2001; Homer & Somers, 1988) and large system programs (Cooper, 1994; Lyneis, Cooper, & Els, 2001). Coyle (1996) provides a survey of applications of system dynamics to military issues. In the current work, system dynamics is used to model ship maintenance operations to generate realistic forecasts of performance. The recent works by Ford, Housel, and Mun (2011) and Ford, Housel, and Dillard (2010) are particularly relevant to the current research because they successfully demonstrated the ability of system dynamics to be integrated with knowledge value added analysis for DoD acquisition.

II. IRM Approach

A. Integrated Risk Management

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 U.S. Department of Defense (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, life-cycle 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 life-cycle 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 3D 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.

B. Data Collection

1. Data Collection Methods

Data on the practices of Dutch industry and naval ship maintenance proved very difficult and time consuming to obtain. Initial contact with Dutch industry participants and ship maintenance technology providers developed slowly over several months into relationships that eventually led to data collection opportunities. Several sources of data were utilized, including a Dutch shipbuilder (Damen) and the Royal Dutch Navy (RDN). Data on the use of technology in Dutch fleet maintenance was collected by two primary methods: (1) in-person interviews and meetings with managers of the leading corporation in the Dutch shipbuilding industry (Damen) and officers and civilian employees of the Royal Dutch Navy, and (2) tours of three Dutch shipbuilding and maintenance facilities.

In-person interviews and meetings with managers of Damen, the leading corporation in the Dutch shipbuilding industry, and officers and a civilian employee of the Royal Dutch Navy occurred during a data collection trip by one of the research team members (Ford) to the Netherlands in June 2012, as did the tours of Dutch ship building and maintenance facilities. Meetings, semi-structured interviews, and extended discussions were held with six managers of Damen Industries and the Royal Dutch Navy in three locations over three days. See Appendix A for a list of informants and site visit locations. At these meetings, Damen managers made presentations on Damen's operations, uses of technologies, investigations of specific technologies for potential development and adoption (including 3D LST and CPLM software), Integrated Logistics System, and information technology products under development for use in ship maintenance[2]. Separately, a meeting and semi-structured interview was conducted with the two Royal Dutch Navy officers responsible for ship maintenance at the RDN shipyard at Nieuwe Haven in Den Helder. Tours of the Royal Dutch Naval fleet maintenance facility in Nieuwe Haven and two Damen shipyards were provided during the data collection trip.

2. Data Collection Results—Damen's Use of Technology

The Damen Shipyards Group (www.damen.nl/) is a large Dutch shipbuilding firm with worldwide operations (11 shipyards with five outside The Netherlands). The firm was started in 1922 by Jan and Rien Damen. The firm grew substantially after Kommer Damen (the current owner) bought it in 1969 and introduced modular and standardized shipbuilding to the industry. The firm now employs over 6,000 persons and builds an average of 150 vessels per year. The firm obtained Damen Schelde, which focuses exclusively on naval ship design, building, and maintenance relatively recently (in 2000). Damen Schelde manufactures an average of one to two ships per year, employs about 550 people, and performs about €210 million per year. Damen Schelde acts as the prime contractor and integrator on its shipbuilding projects, utilizing many subcontractors. Although Damen Schelde provides ship maintenance services to its international (i.e., not Dutch) customers, it does not provide any ship maintenance services for the Royal Dutch Navy.

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[2] Copies of presentations were requested, but not provided. Data collection results are based on notes taken by the investigator during the meetings, interviews, and tours of facilities.

Damen Schelde has used an Integrated Logistics System (ILS) since 2002 to manage the shipbuilding process from project initiation through the development of a logistics plan for customers. The ILS is the plan for the development of a ship and includes ship design, production, QAQC (quality assurance, quality control), training of ship operators, and coordination with customers. The ILS does not include service contracts or life-cycle costs due to the difficulty of forecasting those costs. The focus of the ILS is to provide maximum ship operational availability, reliability, and maintainability. It does this partially by using a single point of contact within Damen throughout the project who manages an interdisciplinary team (e.g., engineering, work preparation, procurement, service). Damen Schelde currently uses a variety of information technologies to facilitate their ILS approach to shipbuilding and is constantly investigating new technologies that may improve their design and manufacturing. Of particular relevance to the current work, Damen Schelde uses four separate software products to manage their shipbuilding: an advanced 3-dimensional CADD program for design, a CPLM product as a database for ship components[3], an Enterprise Resource Planning (ERP) system, and a software tool for scheduling. The latter three of these systems are connected to users with a project information portal developed by Damen Schelde. The informant reported that Damen developed the portal because the CPLM product did not include adequate user interfaces.

Damen Schelde has investigated and is currently investigating other technologies for potential adoption. Four technologies were described and discussed:

1. 3D Laser Scanning Technology (3D LST): This technology was investigated, but was assessed to currently be too immature for adoption by Damen Schelde. The investigation included a discussion of the current use of the technology in the automobile industry, as well as its potential use to scan engine rooms and for floor flattening. The use of 360 degree photography (often used in conjunction with 3D LST) was considered by Damen Schelde as a potential tool for training. See Komoroski (2005) for more details on 3D LST.

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[3] Damen Schelde did not purchase the integrated logistic package available from Siemens.

2. 3D PDF files: 3-dimensional animated "movies" of shipbuilding can be created in a PDF format (by Adobe Acrobat®) and sent to shipyards for use in the field by craftsmen who view the file on an electronic reader (e.g., iPad®). The files would replace flat drawings for use in construction. The file visually communicates the sequence of building (or maintenance) operations and components and operations can have notes attached to them that provide additional information (e.g., part numbers, warnings of special issues). The ability to animate these files allows engineers to visually show craftsmen sequences of operations, routes of access and egress for Line Replaceable Units (LRU[4]), and other information that is difficult or impossible to show with traditional static 2-dimensional drawings. The use of this technology shifts the understanding of the design intention from the designers (in the Netherlands) to the shipbuilding yard (typically in other countries around the world). The use of visual information (the animation of steps) is expected to greatly improve communication across languages, since many of the craftsmen in Damen's shipyards do not read English well. Damen considers improvements in information content communicated to be the primary benefit of this system (versus cost savings). Damen Schelde is very optimistic about the potential for this technology to improve its operations and is actively working on developing it (e.g., selecting software, addressing the importing of the 3D design drawings). Generating the animated files and adding the building steps to the design files is expected to be relatively easy once the system has been developed.

3. SIGMA Shipbuilding Strategy: This is a standardized process for creating a ship that spans from design through materials procurement, production, and testing of a ship. The key feature of the strategy is the use of modular ship sizes and systems that can be easily adapted to specific customer needs. For example, Damen Schelde has disaggregated an entire ship into five standardized modules (e.g., fore, midship, aft) with major systems located in specific sections. Each module is considered a subproject. As an example of an advantage provided by the strategy, the modules and their interfaces are designed such that the ship can be made longer by adding an additional midsection.[5]

4. Radio Frequency Identification (RFID): This established technology is being considered for use to improve Damen's supply chain management. Primary benefits are believed to be improved value of information and a reduction in durations for getting information into Damen databases (e.g.,

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[4] Line Replaceable Unit is a commonly used term in manufactured devices for any modular component that is designed to be interchangeable.

[5] This portion of the SIGMA strategy applies the Boeing strategy for the design and production of the 737 that has different lengths to shipbuilding.

warehouse contents, components on specific ships). Both passive and active tags are being considered.

Damen Services also develops advanced technologies for use by Damen Enterprises. Damen Services focuses on providing ongoing maintenance parts and services to Damen customers after a ship has been designed, built, and delivered, but also provides other services such as civil works (e.g., wharves and storage facilities).

The Maintenance and Spares department maintains information on ship configuration (using an ERP system), parts inventories, and spare parts packages, maintenance management systems. It also provides information technology support for Damen. Damen Services has grown rapidly, from 50 employees in 2008 to 250 employees in 2012. Their primary objective for customers is to reduce costs and increase operational availability. They are developing a web portal for clients that will allow clients access to Damen-held data on each of the customer's ships down to the individual component level. This will partially be accomplished with a work breakdown system (WBS) that disaggregates a ship or system into product parts (e.g., engine, bilge pump) and a functional breakdown system that disaggregates the ship into functions (e.g., port propulsion) that are met with a product part (in the WBS) and have an associated maintenance schedule, which includes monitoring measurements and frequency, parts documentation, and so forth. The WBS has three levels: Subsystems (e.g., propulsion, hoisting) with a typical ship having 20–70 subsystems, Level 2 Parts (e.g., pump, shaft) with about 1,000 per ship, and Level 3 Parts (e.g., bolt, flange) with 70,000–80,000 per ship.

This system will be linked with an online parts ordering portal so that customers can order parts from Damen (similar to Amazon's online selling of books, etc.). Damen Services plans to use the information captured through this system (e.g., frequency of ordering of specific components) to develop maintenance optimization information. Damen Services envisions three types of maintenance: corrective maintenance (after the component needs work), preventative maintenance (based on forecasts of maintenance needs), and condition-based maintenance (based on actual conditions of components). Condition-based maintenance is an optimized version of preventative-based maintenance that is currently under development. It requires sensors to collect data on component conditions that will be used to generate condition assessments.

3. Data Collection Results—Royal Dutch Navy (RDN) Fleet Maintenance

Data collection directly from the RDN was particularly valuable for at least two reasons. First, as the navy of a sovereign country with objectives that are similar to those of the United States, the objectives and issues of the RDN are more likely to match those of the U.S. Navy than those of some other nations. Data collection supported this assumption. For example, technology leadership, interoperability, and reliability in meeting operational needs are paramount to the RDN, and the RDN has recently experienced, and expects to continue to experience, reductions in budgets just as is the case with the U.S. Navy. The Dutch navy continues to face budget cuts and increasing technology needs, is currently in reorganization to reduce total workforce (internal to the navy and civilian naval workforce) by 20%, and is transferring from their legacy information systems to an integrated ERP system for maintenance operations. Second, the RDN performs all of the maintenance on its fleet, thereby making it the primary data source concerning RDN fleet maintenance process performance.

The interviews with the two RDN officers in the Naval Maintenance and Service Agency provided a general introduction to the issues faced by the Dutch navy in building and maintaining its fleet. The RDN addresses its challenges by means similar to those used by the U.S. Navy, such as waiting for technology to mature (technology readiness level [TRL] ≥ 7 before adoption) and incremental capability increases based on budgets. Noticeably different, both the RDN and Damen described the critical role and standard Dutch practice of adjusting requirements to meet budgets in shipbuilding. The RDN is facing increasing pressure to control life-cycle costs in its fleet, which are largely driven by personnel and fuel. This has led them to approve significantly stricter operations manning requirements for ship design (i.e., lower maximum shipboard personnel), which has driven Damen to increase the use of automation in their ship designs.

The primary informant on RDN fleet maintenance operations provided a diagram of those operations (Figure 4) and a written description of each of the steps identified in the diagram.

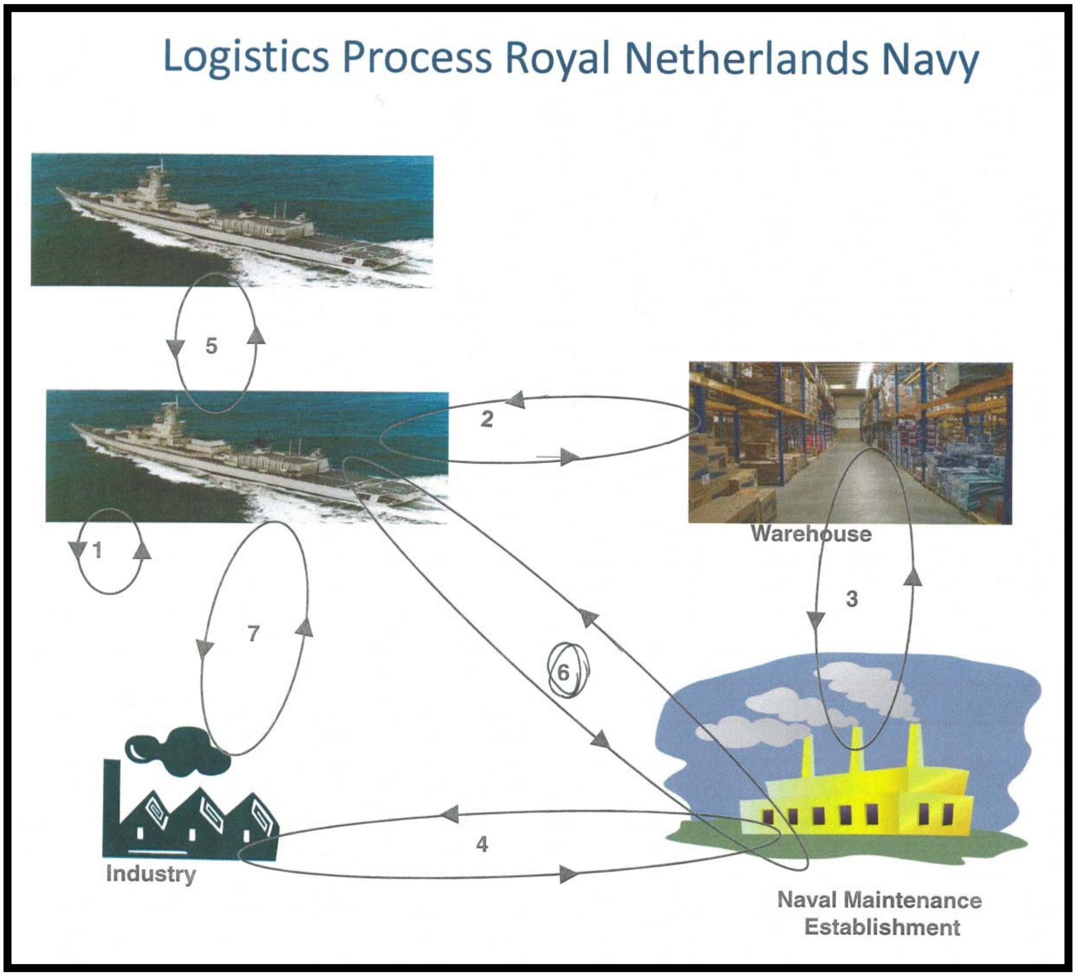

Figure 4. Diagram of Royal Dutch Navy Fleet Maintenance Processes
(Kense, 2012)

The process steps shown in Figure 4 were described in writing by the informant with the following list.[6] In the list, the abbreviation "LRU" stands for "Line Replaceable Unit," a commonly used term in the area of manufactured devices for any modular component that is designed to be interchangeable. MIL-PRF-49506, Notice 1 of 18

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[6] Process step descriptions have been transcribed exactly as provided in English by the RDN, including uncommon English grammar and spelling.

(USAMC Logistics Support Activity, 1996), “Performance Specification for Logistics Management Information,” provides the following definition:

> An LRU is an essential support item which is removed and replaced at the field level to restore the end item to an operational ready condition. Conversely, a non-LRU is a part, component, or assembly used in the repair of an LRU, when the LRU has failed and has been removed from the end item for repair.

C. Logistic Process Royal Netherlands Navy

In case LRU fails the on-board personnel will replace this LRU by a spare (on-board; OLM qualification required).

The defect LRU will be send to the warehouse, and a “new” LRU will be send to the ship.

The defect LRU will be send to the Naval Maintenance Establishment (NME) for repair. After the LRU is repaired it will be send to the warehouse again “as good as new” (DLM qualification required).

If the NME needs parts to repair an LRU, the parts will be extracted from the industry, when the NME is not able to repair this LRU, it can be send to the manufacturer. Also, manpower can be hired to fix problems.

If spare is not available, sometimes it will be cannibalized from another ship.

If the on-board personnel is not able to fix the problem by themselves (due to the complexity of the failure) assistance from the NME is needed (ILM qualification required).

If the problem is too complex for the NME also, the industry can be hired to solve this problem.

The following seven process steps were elaborated on by the informant:

Step 1: Performed onboard, for example to provide operational maintenance of weapons systems

Step 2: Purely a transit operation that requires only a truck driver (if ship is in port)

Step 4: Requires DLM level of training

Step 5: Requires OLM level of training

Step 6: Requires ILM level of training (= LTS + MTS + 10–25 days of training)

Step 7: Requires DLM level of training

The abbreviations DLM, OLM, and ILM refer to Dutch terms for training levels. Fleet maintenance for the RDN requires a minimum of completion of education at a Lower Technical School (LTS) and a Middle/Intermediate Technical School (MTS). The Lower Technical School is typically attended between ages 12–16 and the Middle Technical School is typically attended between ages 16–21. After the completion of LTS and MTS, future RDN ship fleet maintenance personnel must complete at least one of three other forms of training:

- OLM—5–10 days of training
- ILM—10–25 days of training
- DLM—15–35 days of training

Manufacturer training can take either of two alternative training paths:

- LTS then MTS then either OLM or ILM or DLM
- LTS then MTS then OLM then ILM then DLM

The information presented here was augmented by a tour of the Naval Maintenance Establishment (NME) maintenance and repair facilities. The NME provides essentially all maintenance and repair for the RDN fleet and the NME facilities can, and do, perform the required work on RDN ship components. This requires a comprehensive set of equipment and skilled personnel that cover the wide range of materials and components. Examples of testing, maintenance, and repair capabilities seen on the tour include, but are not limited to, the repair of a wide variety of weapons systems, radar systems testing and repair, design and manufacturing of printed circuit boards, and the manufacturing of optical lens for submarine periscopes. NME holds 220,000 total items in the warehouse valued at about €500 million. An average Dutch naval ship contains about 60,000 components.

D. System Dynamics Model Structure

The system dynamics model simulates the movement of LRU among the various locations where they are used, stored, or repaired. These accumulations are referred to as stocks (Sterman, 2000). Each flow of LRUs between two stocks represents the processing rate of one of the process steps in a knowledge value added model. A simplified diagram of the stocks and flows of the model are shown in Figure 5. Boxes represent stocks, or accumulations of LRU. Each stock in Figure 5 represents a location in Figure 4, plus on-board LRU storage as a separate LRU accumulation. Arrows with valve symbols in Figure 5 represent the movement of LRUs between stocks. Numbers in parenthesis in the titles of flows represent the process steps shown in Figure 4 (ovals with arrows) and the KVA model process steps (described later).

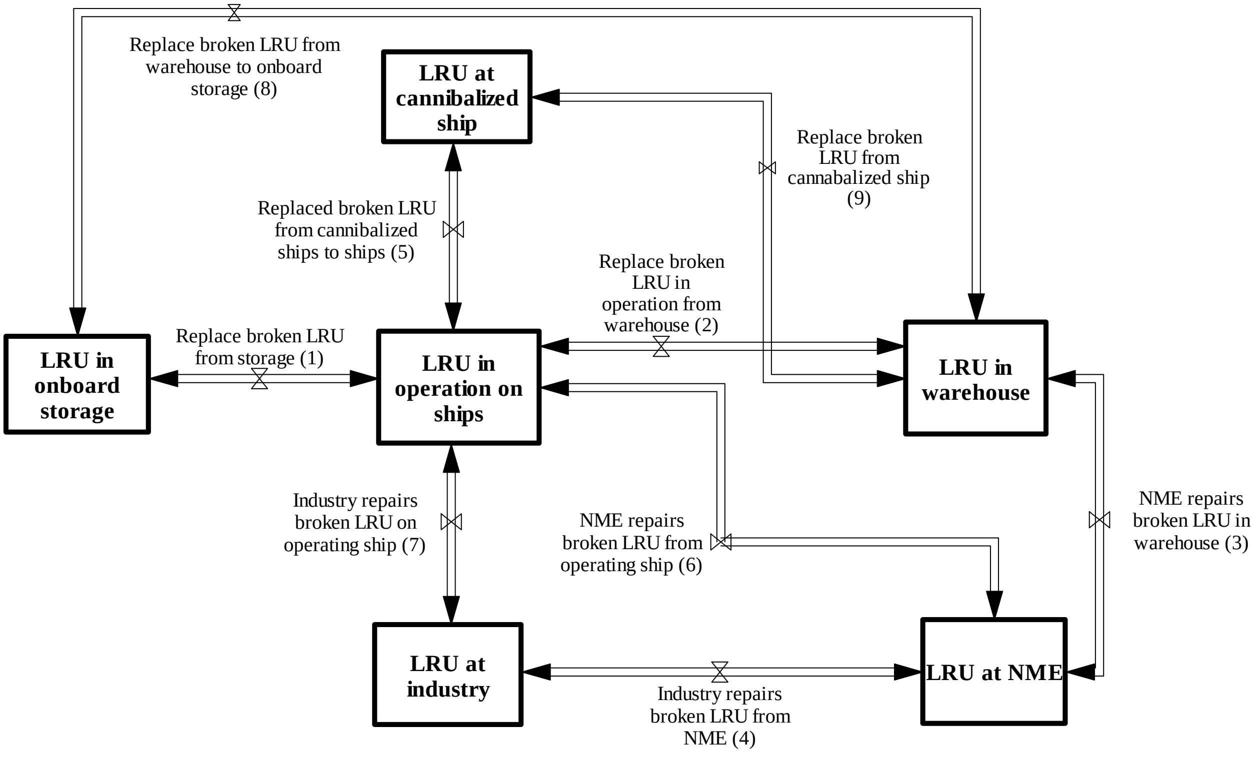

Figure 5. Royal Dutch Navy Ship Maintenance: Stocks and Flows of the System Dynamics Model

The sizes of the flows in the system dynamics model describe the rate of movement of LRUs among the stocks. Therefore, the simulated flows in the system dynamics model become direct inputs to the “times processed per year” portion of the KVA models. Flow rates were modeled to reflect the sequence of processes in operations. For example, in normal operations, the replacement of a broken LRU in an operating ship with one from the ship’s on-board storage (“Replace broken LRU from storage [1]” on left of Figure 5) would be followed by the broken LRU in storage being replaced by an operational LRU from the warehouse (“Replace broken LRU from warehouse on onboard storage [8]” at top in Figure 5). This replacement would be followed by the broken LRU being sent to the NME where it would be repaired and returned to the warehouse (“NME repairs broken LRU in warehouse [3]” on right in Figure 5). These precedencies are modeled by having the downstream process equal to its preceding process step with a delay that reflects the transit and subsequent processing time. Some flows (e.g., NME repairs broken LRU from warehouse [3]) are aggregations of multiple upstream flows. Core flows are based on the mean time between failure of LRUs and the fraction of failures addressed with each process.

The system dynamics model was calibrated to reflect RDN ship maintenance. Quantitative information on the volume of process steps performed in the maintenance of the RDN fleet was requested but was not available, primarily due to the extreme diversity of components and maintenance requirements. One RDN informant described the frequency of the maintenance operations (i.e., Steps 1–7 presented previously) as “continuous” and said that frequency estimates were very difficult because of the extreme range of frequencies across component types. As an example, the informant said that work on some components happens daily while work on other types of components happens only once every few years. The informant provided the example that when a warship was at sea for 30 days only process Step 1 (on-board repairs) would occur, but if the ship were at port other process steps might be used. Therefore, the modeler based calibration for a portion of the system dynamics model on publicly available data, data collected (e.g., numbers of LRU in NME and onboard a typical ship), and estimated conditions of peacetime operations near Dutch ports. Publically available data included the types and numbers of ships in the Dutch navy (”List of Ships,” 2012; Table 2).

Table 2. Royal Dutch Navy Ship Types and Number

Ship Type	Number
Frigate	12
Landing Platform	2
Replenishment	2
Submarine	4
Mine detection	6
Dive support	4
Hydrographical survey	2
Training	2
Tugs - large	5
Tugs - harbor	7
Landing craft	17
Patrol boat - off shore	4
Patrol boat - in shore	6
Cutter	3
TOTAL	**76**

Calibration estimates were made using this information as follows. Data not documented in Table 2 are modeler estimates.

> Total LRU in use on all ships = 60k LRU/ship * 76 ships = 4,560k LRU on ships

Assuming one ship of each of the 14 ship types is considered "sacrificial" and used for cannibalization, then

> Total LRU in use on the 62 (= 76–14) "operating" ships = 62 ships * 60k LRU/ship = 3,720k LRU
>
> Total LRU in use on the 14 "sacrificial" ships = 4,560k – 3,720k = 840k LRU

In addition, each ship keeps 25% of its LRU in on-board ship storage:

> 62 ships * (25%)(60k LRU/ship) = 930k LRU in storage on operating ships
>
> 14 ships * (25%)(60k LRU/ship) = 210k LRU in storage on sacrificial ships
>
> Total LRU on sacrificial ships = 840k + 210k = 1050k LRU on sacrificial ships

The warehouse initially holds one complete set for each vessel type:

60k LRU/ship * 14 ship types = 840k LRU

The number of LRU at NME is only the LRU that are currently being repaired by NME (i.e., all LRU storage occurs at the warehouse and none at NME [consistent with researcher observations]).

The following fractions of broken LRUs are addressed with each solution:

25% of broken LRU are replaced with on-board replacements[7]

10% of broken LRU are cannibalized from other ships[8]

35% of broken LRU are replaced with LRU in warehouse[9]

25% of broken LRU are repaired by NME directly without passing through warehouse

5% of broken LRU are repaired directly by industry

100% TOTAL

The estimates assume that 15% of LRU repaired directly by NME need assistance from industry.

E. KVA Models to the Royal Dutch Navy Ship Maintenance

Four knowledge value added models were built based on the Royal Dutch Navy Ship Maintenance processes:

1. Baseline RDN ship maintenance processes
2. Baseline RDN ship maintenance processes changed to reflect the adoption and use of a logistics package from an integrated CPLM system such as was investigated by Damen

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[7] These LRU are then sent to the warehouse and replaced with an operational LRU from the warehouse.

[8] These LRU are then sent to the warehouse and replaced with an operational LRU from the warehouse.

[9] These LRU are then sent to the NME for repair and returned to the warehouse.

3. Baseline RDN ship maintenance processes changed to reflect the adoption and use of 3D PDF modeling managed with a CPLM system as planned by Damen

4. Baseline RDN ship maintenance processes changed to reflect the adoption and use of a logistics package and 3D PDF modeling managed by an integrated CPLM system

Inputs to these models were generated as follows:

Process Descriptions—The seven basic process steps used by the RDN to maintain the fleet were taken from data collected from the RDN (Figure 4) and descriptions provided by the manager of the NME. Two additional process steps (8 and 9) were added based on the logic that broken LRU in onboard storage or cannibalized ships would be replaced with operating LRU from the warehouse.

Title of Head Process Executer—The KVA modeler matched the levels and types of training received in the different levels of training as described by the informants to the process steps based on process step requirements.

Number of Employees—The KVA modeler's estimate based on manpower requirements to perform each process step in the maintenance of pumps scenario.

Corresponding Pay Grades—The KVA modeler's estimate of relative hourly pay rates for skill levels described by training requirements. Estimated values include labor burden and overhead.

Rank Order of Difficulty—The KVA modeler's estimate based on understanding of processes from informants.

Actual Average Training Period—Based on data provided by informants (see previous data description).

Percentage Automation—The KVA modeler's estimate in the base case based on understanding of processes from informants. Modeler's estimate of changes due to technology adoptions based on previous KVA models of ship maintenance processes.

Times performed in a Year—Output from the system dynamics model.

Average Time to Complete—The KVA modeler's estimate for the base case based on understanding of processes from informants. The modeler's estimate of changes due to technology adoptions for other KVA models.

Automation Tools—The KVA modeler's estimate for the base case based on understanding of processes from informants. The modeler's estimate of changes due to technology adoptions for other KVA models.

F. Model Simulations and Results

The system dynamics model was simulated to represent the four technology adoption scenarios described in the previous section. The output of each system dynamics model simulation was used as input to a KVA model. Those KVA models were then used to estimate the return on investment (ROI) of each process in each of the four scenarios and the cumulative ROI for each scenario. The results based on the models and their calibrations described previously are shown in Table 3.

Table 3. Knowledge Value Added Model Results

		Return On Investment (ROI)			
	Process Description	**Baseline**	**Add Logistics**	**Add 3D PDF**	**Add Logistics & 3D PDF**
1	Replace LRU with on-board spare	90%	261%	501%	464%
2	Replace operating LRU with warehouse spare	90%	151%	621%	1027%
3	NME repairs warehouse LRU and returns it to warehouse	8%	65%	95%	236%
4	Manufacturer repairs LRU for NME & it returns to warehouse	31%	88%	168%	168%
5	Replace on-board LRU with LRU cannibalized from another ship	90%	151%	621%	1027%
6	NME repairs on-board LRU and returns it to ship	265%	10%	99%	192%
7	Industry repairs on-board LRU and returns it to ship	34%	178%	135%	318%
8	Replace on-board storage LRU with warehouse spare (transit only)	301%	759%	759%	759%
9	Replace cannabalized LRU with warehouse spare (transit only)	140%	329%	862%	1102%
	TOTAL ALL PROCESSES	35%	77%	135%	274%

Although increased throughput due to reduced processing durations (which increase the ROI numerator) can partially explain differences in the ROI in Table 3, cost reduction (which decreases the ROI denominator) is the primary driver of increases in ROI. For example, processes 8 and 9 are benefitted by reductions in rework (e.g., errors in transporting LRU) due to the adoption of a logistics package. This reduces the number of transport trips required (the function of these processes), thereby significantly reducing costs and increasing the ROI. In contrast, processes 3, 4, and 6 are highly skilled processes that are difficult to replace with technology and, therefore, benefit less from technology adoption than other processes. This results in a smaller increase in ROI for these processes.

G. Analysis of Simulation Model Results

A variance analysis was performed on the KVA model results (Table 3) to evaluate the relative impacts of the adoption of different technologies (Table 4). Returns on investment for each of the three technology adoption alternatives were compared with the baseline returns on investment to estimate improvement due to technologies (left three columns of results, Table 4). In addition, the improvement from adopting both technologies over adopting only the 3D PDF technology was estimated (right column, Table 4)

Table 4. Variance Analysis of KVA Model Results

		Return On Investment (ROI)			
	Process Description	**Add Logistics - Improvement over Baseline**	**Add 3Dpdf - Improvement over Baseline**	**Add Logistics & 3Dpdf - Improvement over Baseline**	**Add Logistics & 3Dpdf - Improvement over adding only 3Dpdf**
1	Replace LRU with on-board spare	171%	411%	374%	-38%
2	Replace operating LRU with warehouse spare	61%	532%	937%	406%
3	NME repairs warehouse LRU and returns it to warehouse	57%	87%	227%	140%
4	Manufacturer repairs LRU for NME & it returns to warehouse	57%	138%	138%	0%
5	Replace on-board LRU with LRU cannibalized from another ship	61%	532%	937%	406%
6	NME repairs on-board LRU and returns it to ship	-256%	-166%	-73%	93%
7	Industry repairs on-board LRU and returns it to ship	145%	101%	284%	183%
8	Replace on-board storage LRU with warehouse spare (transit only)	458%	458%	458%	0%
9	Replace cannabalized LRU with warehouse spare (transit only)	189%	721%	962%	240%
	TOTAL ALL PROCESSES	**42%**	**100%**	**239%**	**139%**

Referring to Table 4, adding either or both of the technologies improves overall ship maintenance ROI, as indicated by the positive numbers in the last row of Table 4. Adopting 3D PDF alone improves ROI significantly more than adopting a logistics package alone (100% improvement > 46% improvement) and adding both technologies improves ROI more than adding either technology alone (239% improvement > 42% improvement or 100% improvement), suggesting that there may be synergy between the technologies. This is also supported by the 139% improvement by adding logistics if 3D PDF is already in place (lower right result in Table 4).

Adopting the technologies does not impact the ROI of individual processes equally. Among the seven core processes(1–7)[10] adding only a logistics package (left column of results in Table 4) increases the "Replace LRU with on-board spare" (process 1) most, by 171%, and decreases the return of process 6, "NME repairs on-board LRU and returns it to ship" by 256%. Among the seven core processes, adding only 3D PDF increases processes 2 and 5, "Replace operating LRU with warehouse spare" and "Replace on-board LRU with LRU cannibalized from another shop" most, by 532%, and decreases the return of process 6, "NME repairs on-board LRU and returns it to ship" by 166%. Among the seven core processes, adding both technologies increases processes 2 and 5, "Replace operating LRU with warehouse spare" and "Replace on-board LRU with LRU cannibalized from another shop" most, by 937%, and decreases the return of process 6, "NME repairs on-board LRU and returns it to ship," by 73%.

H. Comparison of Royal Dutch Navy and U.S. Navy Scenarios

Previous research using the KVA approach developed estimates of returns on technology investment of a scenario in which the U.S. Navy adopts 3D laser scanning technology (3D LST) and collaborative product lifecycle management (CPLM) tools into the SHIPMAIN program. Komoroski (2005) investigated the early phases of SHIPMAIN. The relevant results are shown in Table 5.

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[10] Process 8, "Replace on-board storage LRU with warehouse spare (transit only)" supports process 1, "Replace LRU with on-board spare." Therefore process 1 is the core process. Similarly, process 9, "Replace cannibalized LRU with warehouse spare (transit only)" supports process 5, "Replace on-board LRU with LRU cannibalized from another ship." Therefore process 5 is the core process.

Table 5. Preparation for Maintenance Processes—As-Is and Radical ROI Differences

Core Process	Process Title	"AS_IS" ROI	"RADICAL" ROI	"RADICAL" improvement over "AS-IS"
1	ISSUE TASKING	-59%	-59%	0%
2	INTERPRET ORDERS	-73%	746%	819%
3	PLAN FOR SHIPCHECK	-99%	-95%	4%
4	CONDUCT SHIPCHECK	-74%	1653%	1727%
5	REPORT ASSEMBLY	-39%	1032%	1071%
6	REVISE SCHEDULE	12%	882%	870%
7	GENERATE DRAWINGS	-54%	2977%	3031%
	TOTALS	**-27%**	**2019%**	**2045%**

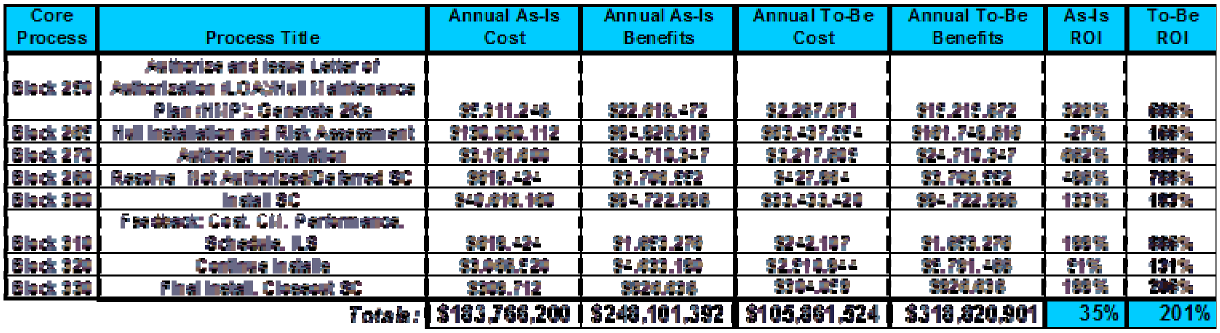
Note. This table is based on Komoroski (2005).

Referring to Table 5, adding the 3D LST and CPLM technologies improves overall preparation for maintenance process ROI, as indicated by the positive number in the lower right corner of Table 5. Adding these technologies generally improves individual processes as well, as indicated by the non-negative (and positive with one exception) numbers in the right column of Table 5. The range of improvements across individual processes is large, varying from 0% (Issue Tasking) to 3031% (Generate Drawings). Cost reduction explains these differences. For example, the adoption of technology in Core Processes 4 (Conduct Shipcheck) and 7 (Generate Drawings) significantly reduce the number of people required to survey ship conditions (4) or draft 3D drawings from the survey data (9), resulting in large ROI if the technology is adopted.

Seaman, Housel, and Mun (2007) used KVA to model the later phases of SHIPMAIN. The relevant results are shown in Table 6.

Table 6. Maintenance Implementation Processes—As-Is and To-Be ROI Comparison

(Seaman, Housel, & Mun, 2007)



Core Process	Process Title	Annual As-Is Cost	Annual As-Is Benefits	Annual To-Be Cost	Annual To-Be Benefits	As-Is ROI	To-Be ROI
Block 250	Authorize and Issue Letter of Authorization (LOA)/Hull Maintenance Plan (HMP); Generate 2Ks	$5,311,248	$22,019,472	$2,267,471	$15,215,872	320%	588%
Block 265	Hull Installation and Risk Assessment	$130,990,112	$94,926,916	$93,437,554	$161,749,616	-27%	166%
Block 270	Authorize Installation	$3,161,600	$24,710,347	$3,217,695	$24,710,347	682%	688%
Block 280	Resolve Not Authorized/Deferred SC	$919,424	$3,706,552	$427,694	$3,706,552	408%	788%
Block 300	Install SC	$40,016,160	$94,722,996	$33,433,420	$94,722,996	133%	183%
Block 310	Feedback: Cost, CM, Performance, Schedule, ILS	$919,424	$1,653,278	$242,107	$1,653,278	180%	588%
Block 320	Continue Installs	$3,066,520	$4,633,190	$2,510,944	$5,791,488	51%	131%
Block 330	Final Install, Closeout SC	$309,712	$926,636	$304,059	$926,636	180%	208%
	Totals:	$183,766,200	$248,101,392	$105,861,524	$318,820,901	35%	201%

Referring to Table 6, adding the technologies also improves overall maintenance implementation process ROI, as indicated by the positive difference between the overall To-Be ROI (201%) and the overall As-Is ROI (35%) numbers in the lower right corner of Table 6. Adding these technologies also improves each of the individual processes, as indicated by the increases in the To-Be ROI values over the As-IS ROI values in Table 5. The range of improvements across individual processes is large, varying from 6% to 466% (Final Install, Closeout SC), although not as wide as in the preparation for maintenance processes.

Although the same KVA modeling process was applied to ship maintenance in both the U.S. and the Royal Dutch navies, the KVA models have important differences that complicate the comparison of their results. For example, the process steps are different and the amount of field data available to calibrate the models differ significantly. Therefore, any comparisons can only be preliminary at this point. However, comparison can reveal some apparent similarities and differences between the scenarios that are of interest. Table 7 shows the overall baseline (existing processes) and technology-improved ROI for the two U.S. Navy scenarios and the Royal Dutch Navy scenario.

Table 7. Return on Investment: Baseline and Technology Adoption Scenarios

	Baseline Overall ROI	Technology-adopted Overall ROI
US Navy - SHIPMAIN (preparation for maintenance phases)	-27%	2019%
US Navy - SHIPMAIN (implementation phases)	35%	201%
Royal Dutch Navy (Damen experience extrapolation)	35%	274%

The three scenarios have some similarities. For all three, overall returns on investment after technology adoption are positive and large. This supports the adoption of advanced technologies, such as 3D laser scanning technology, 3D PDF models, and collaborative product lifecycle management, to improve the efficiency of resource use. The scenarios also have potentially significant differences. The technology-adoption scenario for the preparation for maintenance phases of the U.S. scenario has a much higher overall ROI than the ROIs for the maintenance implementation phases of the U.S. or the Dutch scenario (2,019% >> 201% or 274%). Several factors could explain these differences.

- The preparation for maintenance phases of the U.S. scenario have significantly lower ROI in the As-Is (without technology) condition (-27% > 35%). This suggests that inefficiencies in the preparation for maintenance processes provided more and larger opportunities for improvement.

- The individual preparation for maintenance processes that increased the most (see Table 5) such as Generate Drawings and Conduct Shipcheck are very labor intensive and, therefore, costly, providing large opportunities for cost reduction through technology adoption.

- Several of the individual maintenance implementation processes (Table 6) are labor intensive, but less impacted by technology (e.g., Install Shipcheck), thereby making those changes in ROI less dramatic.

- The preparation for maintenance phases of the U.S. scenario could be more optimistic in their projections than the other scenarios.

- The estimates of process changes may use different assumptions.

- Technologies adopted in the preparation for maintenance phases of the U.S, scenario may make much larger improvements in processes than those in the maintenance implementation phases of the U.S. or the Dutch scenario.

- The Dutch case does not use all of the capabilities of the CPLM, thereby making it more incremental than the U.S, scenarios, where all the capabilities of the CPLM were projected to be used. Also, 3D PDF has more limited capabilities for integration with the CPLM logistics package when compared to the integration of 3D LST capabilities for broader usage in requirements analysis, planning for maintenance, and tracking of parts in the supply chain and across suppliers and contractors. This can partially explain the lower ROI for the Dutch technology-adopted scenario than the U.S. preparation for maintenance scenario.

- The projections of the impacts on the maintenance implementation phases of the U.S, scenario and the Dutch scenario may be rather conservative based on research into the actual successful implementation of other modern technologies, such as RFID in inventory management. In a study of the actual use of passive RFID in two military warehouses in the Korean Air Force and Army, the actual ROIs from use of the RFID technology were more than triple the projected impact of the use of the technology in a separate study of the U.S. Navy (Courtney, 1997). The Korean ROIs after actual implementation of the RFID technology ranged from 610% to 576%, compared to the projected returns anticipated from the implementation of the same technology in the U.S. Navy, which ranged up to 133%. The implication is that actual successful implementation of information technology in a military may exceed projections of the potential impacts of the technology. It follows that the current research on the impacts of CPLM and 3D LST or 3D PDF may be more conservative than the reality once these technologies are actually implemented on a wide-scale basis.

I. Integrated Risk Management Modeling and Results

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 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.

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 4.[11] In the handbook, the three main distributions recommended are the triangular, normal, and uniform distributions. We choose 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. Using these AFCAA guidelines, which are presented as 15%, Mean, and 85% values (Figure 6), we imputed the corresponding minimum (min), most likely (likely), and maximum (max) values required in setting up the Triangular distributions (Figure 7).[12]

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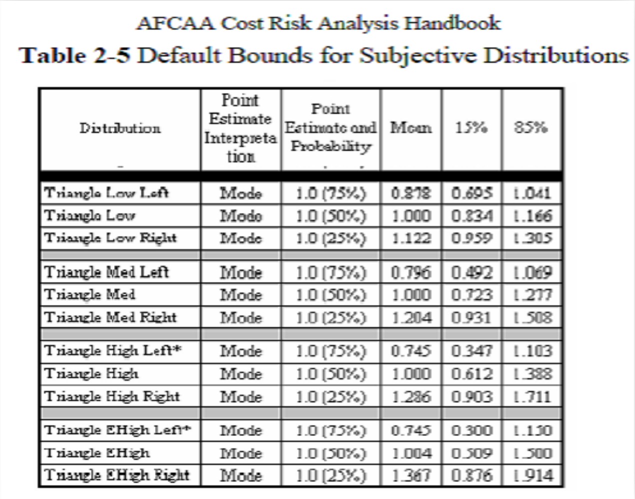
[11] Available at http://www.afhra.af.mil/factsheets/factsheet.asp?id=14009

[12] Using the Triangular distribution's probability density function (PDF), we simply compute the cumulative distribution function (CDF). In mathematics and Monte Carlo simulation, a PDF represents a continuous probability distribution in terms of integrals. If a probability distribution has a density of f(x), then intuitively the infinitesimal interval of [x, x + dx] has a probability of f(x) dx. The PDF, therefore, can be seen as a smoothed version of a probability histogram; that is, by providing an empirically large sample of a continuous random variable repeatedly, the histogram, using very narrow ranges, will resemble the random variable's PDF. The probability of the interval between [a, b] is given by $\int_a^b f(x)dx$, which means that the total integral of the function f must be 1.0. The CDF is denoted as F(x) = P(X ≤ x), indicating the probability of X taking on a less than or equal value to x. Every CDF is monotonically increasing, is continuous from the right, and at the limits, and has the following properties: $lim_{x\to-\infty} F(x) = 0$ and $lim_{x\to+\infty} F(x) = 1$. Further, the CDF is related to the PDF by $F(b) - F(a) = P(a \leq x \leq b) = \int_a^b f(x)dx$, where the PDF function *f* is the derivative of the CDF function *F*. Using these relationships, we can impute the min, likely, and max values from the mean, and the 15th and 85th percentiles that were provided by the AFCAA.

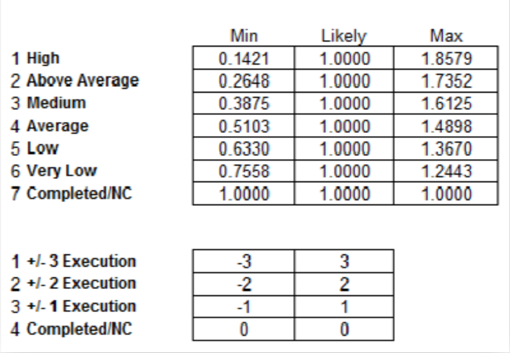


AFCAA Cost Risk Analysis Handbook

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	1.130
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 6. U.S. Air Force Cost Analysis Agency (US. AFCAA) Handbook's Probability Risk Distribution Spreads
(available at http://www.afhra.af.mil/factsheets/factsheet.asp?id=14009)



Symmetrical Spreads (Tringular Distribution)

	Min	Likely	Max
1 High	0.1421	1.0000	1.8579
2 Above Average	0.2648	1.0000	1.7352
3 Medium	0.3875	1.0000	1.6125
4 Average	0.5103	1.0000	1.4898
5 Low	0.6330	1.0000	1.3670
6 Very Low	0.7558	1.0000	1.2443
7 Completed/NC	1.0000	1.0000	1.0000

1 +/- 3 Execution	-3	3
2 +/- 2 Execution	-2	2
3 +/- 1 Execution	-1	1
4 Completed/NC	0	0

Figure 7. U.S. AFCAA Handbook's Probability Risk Distribution Spreads

It is important to understand why it is necessary to apply uncertainty to the model. Because the KVA process provided a point value for each quantity, even though there is some uncertainty in the estimates provided by the SMEs, application of the appropriate statistical distributions of input is used to restore the real world's uncertainty to the model. Having inputs from only three experts, as opposed to hundreds of estimates, and rather than using these three discrete inputs, we applied the lessons learned in cost estimating as reflected in the Air Force handbook as a good starting point for representing the uncertainty and reflecting it in the simulations.

Next, using the developed KVA model, risk simulation probabilistic distributional input parameters are inserted into the three main variables: Percentage Automation, Time Process Is Executed, and Average Time to Complete (Figure 8).[13] A risk simulation of 10,000–1,000,000 simulation trials was run to obtain the results.[14]

Two sets of results important in the simulation analysis are volatility and probability confidence intervals. The simulation statistics obtained after running a simulation can be seen in Figure 9, where the main variable of interest is the coefficient of variation, which in this case is used as a proxy for volatility.[15] The average volatilities are between 54% and 87%. To put this into perspective, the annualized volatility of blue chip stocks (e.g., IBM or Microsoft) is typically between 15% and 30%, whereas higher risk companies (stocks with low market-to-book ratios, low price-to-earnings ratios, or startups) have their stocks' volatilities above 50%, and highly speculative derivatives may have volatilities upwards of 100%.

The probability confidence intervals will be used and discussed in a later section within the realm of real options valuation.

At this point in the analysis, a proxy for revenues and volatility has been identified, as well as the numerators and denominators for the ship maintenance

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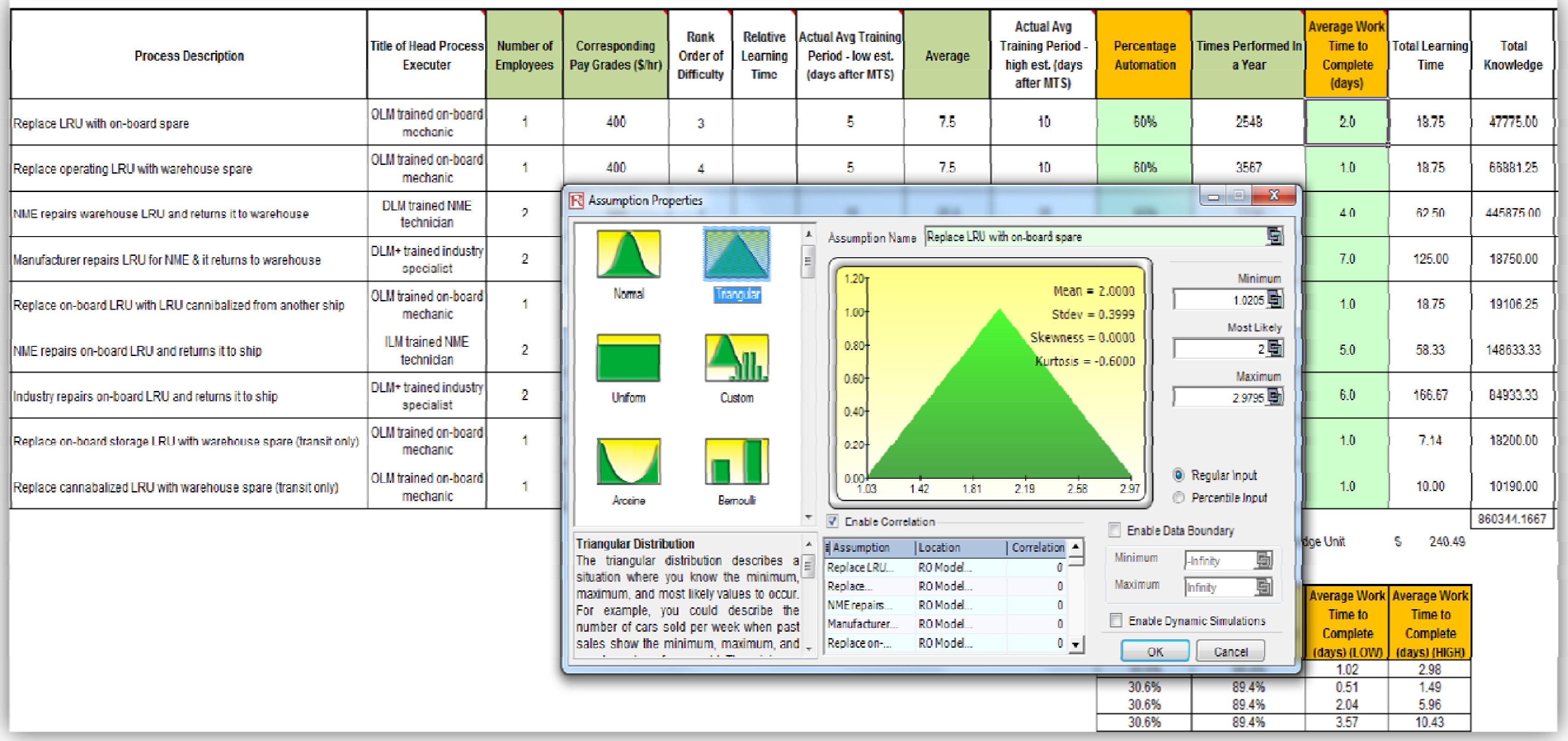
[13] The Monte Carlo Risk Simulation was performed using Risk Simulator (version 2012) software by Real Options Valuation, Inc. (www.realoptionsvaluation.com), and screenshots provided are with permission from the software developers.

[14] Different numbers of trials were run to calibrate the precision of the model and to check for model convergence.

[15] The coefficient of variation is simply defined as the ratio of standard deviation to the mean, where risks are common size. As standard deviation is the measure of the spread or dispersion of the data around its mean, it is oftentimes used as a measure of uncertainty and, when divided by the average of the distribution, it becomes a relative measure of risk, without any units. This measure of risk or dispersion is applicable when the variables' estimates, measures, magnitudes, or units differ, and can be used as a proxy for volatility of the project.

program. The next step is to define or frame the alternatives and approaches to implementing 3D PDF and Logistics Team Centers, namely, strategic real options. The questions that can be answered include the following: What are the options involved?; How should these new processes be best implemented?: Which decision pathway is optimal?; and How much is the program worth to the DoD?



Process Description	Title of Head Process Executer	Number of Employees	Corresponding Pay Grades ($/hr)	Rank Order of Difficulty	Relative Learning Time	Actual Avg Training Period - low est. (days after MTS)	Average	Actual Avg Training Period - high est. (days after MTS)	Percentage Automation	Times Performed In a Year	Average Work Time to Complete (days)	Total Learning Time	Total Knowledge
Replace LRU with on-board spare	OLM trained on-board mechanic	1	400	3		5	7.5	10	60%	2548	2.0	18.75	47775.00
Replace operating LRU with warehouse spare	OLM trained on-board mechanic	1	400	4		5	7.5	10	60%	3567	1.0	18.75	66881.25
NME repairs warehouse LRU and returns it to warehouse	DLM trained NME technician	2									4.0	62.50	445875.00
Manufacturer repairs LRU for NME & it returns to warehouse	DLM+ trained industry specialist	2									7.0	125.00	18750.00
Replace on-board LRU with LRU cannibalized from another ship	OLM trained on-board mechanic	1									1.0	18.75	19106.25
NME repairs on-board LRU and returns it to ship	ILM trained NME technician	2									5.0	58.33	148633.33
Industry repairs on-board LRU and returns it to ship	DLM+ trained industry specialist	2									6.0	166.67	84933.33
Replace on-board storage LRU with warehouse spare (transit only)	OLM trained on-board mechanic	1									1.0	7.14	18200.00
Replace cannabalized LRU with warehouse spare (transit only)	OLM trained on-board mechanic	1									1.0	10.00	10190.00
													860344.1667

dge Unit $ 240.49

		Average Work Time to Complete (days) (LOW)	Average Work Time to Complete (days) (HIGH)
		1.02	2.98
30.6%	89.4%	0.51	1.49
30.6%	89.4%	2.04	5.96
30.6%	89.4%	3.57	10.43

Assumption Properties

Assumption Name: Replace LRU with on-board spare

Minimum: 1.0205

Most Likely: 2

Maximum: 2.9795

Mean = 2.0000

Stdev = 0.3999

Skewness = 0.0000

Kurtosis = -0.6000

● Regular Input

○ Percentile Input

☑ Enable Correlation

Assumption	Location	Correlation
Replace LRU...	RO Model...	0
Replace...	RO Model...	0
NME repairs...	RO Model...	0
Manufacturer...	RO Model...	0
Replace on-...	RO Model...	0

☐ Enable Data Boundary

Minimum: -Infinity

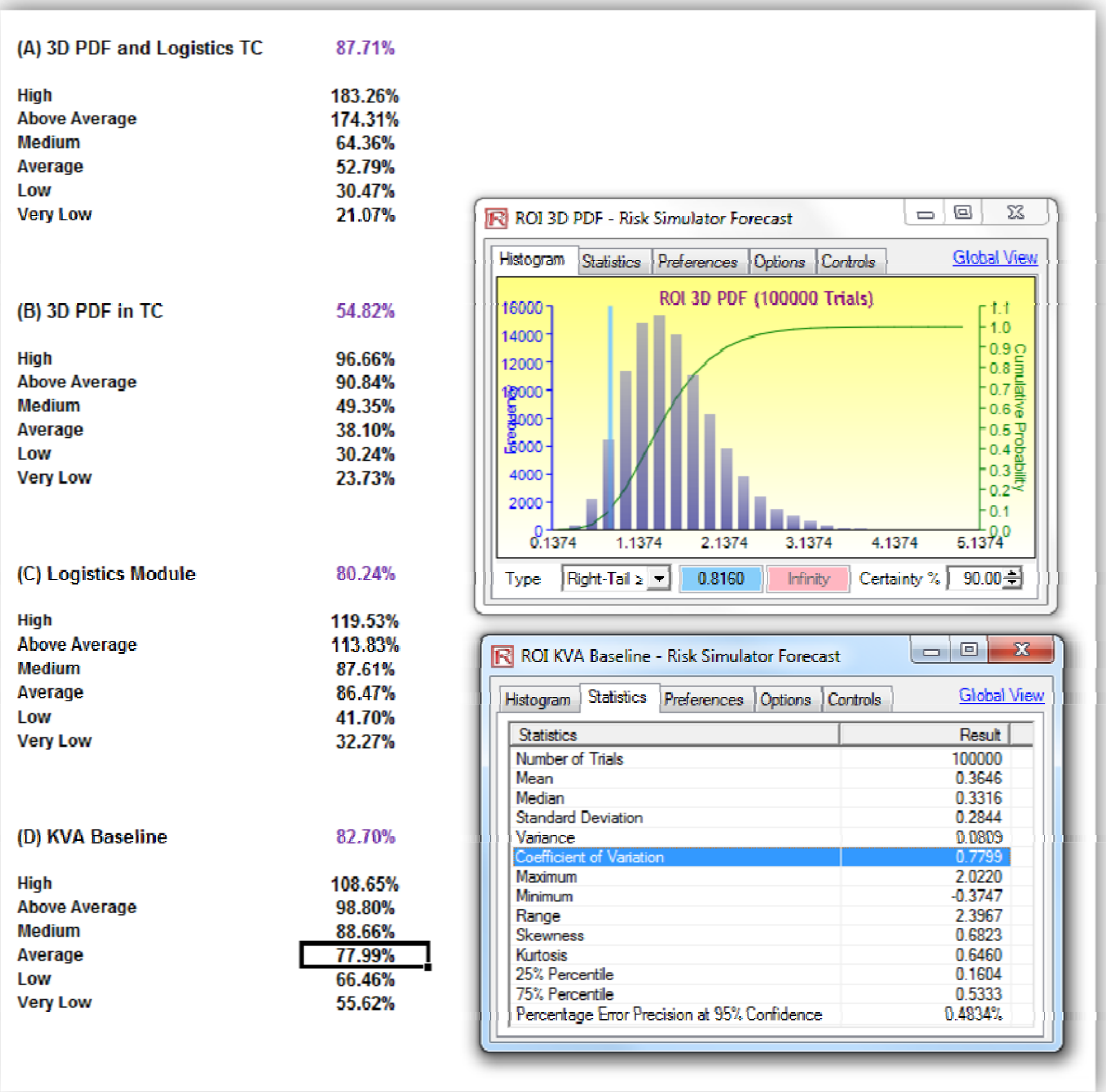
Maximum: Infinity

☐ Enable Dynamic Simulations

Triangular Distribution

The triangular distribution describes a situation where you know the minimum, maximum, and most likely values to occur. For example, you could describe the number of cars sold per week when past sales show the minimum, maximum, and

Figure 8. Risk Simulation Probability Distribution Parameters



(A) 3D PDF and Logistics TC	87.71%
High	183.26%
Above Average	174.31%
Medium	64.36%
Average	52.79%
Low	30.47%
Very Low	21.07%

(B) 3D PDF in TC	54.82%
High	96.66%
Above Average	90.84%
Medium	49.35%
Average	38.10%
Low	30.24%
Very Low	23.73%

(C) Logistics Module	80.24%
High	119.53%
Above Average	113.83%
Medium	87.61%
Average	86.47%
Low	41.70%
Very Low	32.27%

(D) KVA Baseline	82.70%
High	108.65%
Above Average	98.80%
Medium	88.66%
Average	77.99%
Low	66.46%
Very Low	55.62%

Statistics	Result
Number of Trials	100000
Mean	0.3646
Median	0.3316
Standard Deviation	0.2844
Variance	0.0809
Coefficient of Variation	0.7799
Maximum	2.0220
Minimum	-0.3747
Range	2.3967
Skewness	0.6823
Kurtosis	0.6460
25% Percentile	0.1604
75% Percentile	0.5333
Percentage Error Precision at 95% Confidence	0.4834%

Figure 9. Risk Simulated Volatility

J. IRM: Why 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.[16] See the Appendix B for more details on IRM and real options analysis.

K. IRM: Framing the Real Options

As part of the first round of preliminary analysis, Figure 10 illustrates some of the potential implementation paths for 3D PDF/Logistics TC. Clearly some of the pathways and flexibility strategies may be refined and updated through the passage of time,

---

[16] The pathways can be valued using partial differential closed-form equations, lattices, and simulation. The Real Options SLS software, version 2012 (B), by Real Options Valuation, Inc. (www.realoptionsvaluation.com), is used to value these options with great ease. Monte Carlo risk simulations were performed using the Risk Simulator software, version 2012 (B), created by the same organization.

actions, and events. With the evolution of the implementation, valuable information is obtained to help in further fine-tuning the implementation and decision paths.

For the preliminary analysis, the following options were identified, subject to modification:

> Option A: As-Is Base Case. The ROI for this strategic path is computed using the baseline KVA and this represents the current Royal Dutch Navy ship maintenance process (i.e., no newly added technologies).
>
> Option B: Execute and implement 3D PDF and Logistics package immediately across all Royal Dutch Navy ship maintenance processes. That is, take the risk and execute on a larger scale, where you would spend the initial investments and continuing maintenance expenses required and take on the risks of any potential failure, but reap the rewards of the new processes' savings quickly and immediately. The analysis is represented as the current RDN process altered to reflect what we estimate to be the impacts of adopting both a Logistics package and 3D PDF models.
>
> Option C: This represents the current RDN process altered to reflect what we estimate to be the impacts of adopting 3D PDF models and managing them in a Team Center or similar product. This technology was chosen largely because Damen is developing and pursuing the use of this technology.
>
> Option D: This implementation pathway represents the current RDN process altered to reflect what we estimate to be the impacts of managing using a Logistics module in a Team Center or similar product. This technology was chosen partially because it was a technology that Damen considered, but chose not to purchase.
>
> Option E: Proof of Concept approach, that is, to execute large-scale implementation of 3D PDF and Logistics Module in TC only after an initial Proof of Concept (POC) shows promising results. If POC turns out to be a failure, we walk away and exit the program, and losses are minimized and limited to the initial POC expenses. Proceed to full implementation in POC programs first and then expand in sequential fashion to other programs, based on where best ROI estimates are shown.
>
> Option F: Proof of Concept on 3D PDF only. Assuming the POC works and 3D PDF is executed within a few programs successfully, the learning and experience obtained becomes valuable and allows the shipyard to expand its use into many other programs or perhaps across the Royal Dutch Navy.

Option G: Proof of Concept on Logistics Module in TC only. Assuming the POC works and Logistics Module is executed within a few programs successfully, the learning and experience obtained becomes valuable and allows the shipyard to expand its use into many other programs or perhaps across the Royal Dutch Navy.

Figure 11 shows the preliminary input assumptions and Figure 12 shows the computed return on investment results and strategic real options results. For instance, the following inputs were assumed:

PV Asset. This is the net total benefits or proxy revenues (numerator) obtained from the KVA analysis under each of the various options as outlined previously.

Implementation Cost. This is the total cost to implement each of the options (e.g., 3D PDF only, 3D PDF with Logistics Module TC, or Logistics Module TC only).

Maturity. This is the time to perform the proof of concept stage, denoted in years.

Risk-Free Rate. This is the annualized U.S. Treasury rate used as a proxy of a risk-free asset. This rate is used to discount the future cash flows in the risk-neutral options model. We use a risk-free rate as the risk has already been accounted for in the risk simulation and volatility estimates. Figure 13 illustrates the U.S. Treasury security interest rates used as a proxy for the risk-free rate used in the analysis.

Volatility. This is the annualized volatility estimate obtained from Monte Carlo risk simulation in the previous step by using the AFCAA risk spreads as a proxy.

Dividend Rate. This variable is typically not used but is available should the need arise. Briefly, it measures the annualized percentage rate of the opportunity cost of investing at a future time instead of immediately.

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III. IRM: Strategic Flexibility Real Options Results

Figure 12 shows the results of the strategic real options flexibility values and compares them against the KVA ROI values. Options B ($154.1 million at 278% ROI) and E ($156.5 million at 282% ROI) of implementing both 3D PDF and Logistics Module TC return the highest ROI and total strategic value, and both provide a significant value-add above and beyond Option A's As-Is condition ($31.9 million at 35% ROI). As Options B and E are the most significant, stage-gating the implementation over several phases yields a slightly higher value (Option E exceeds Option B by about $2.4 million).

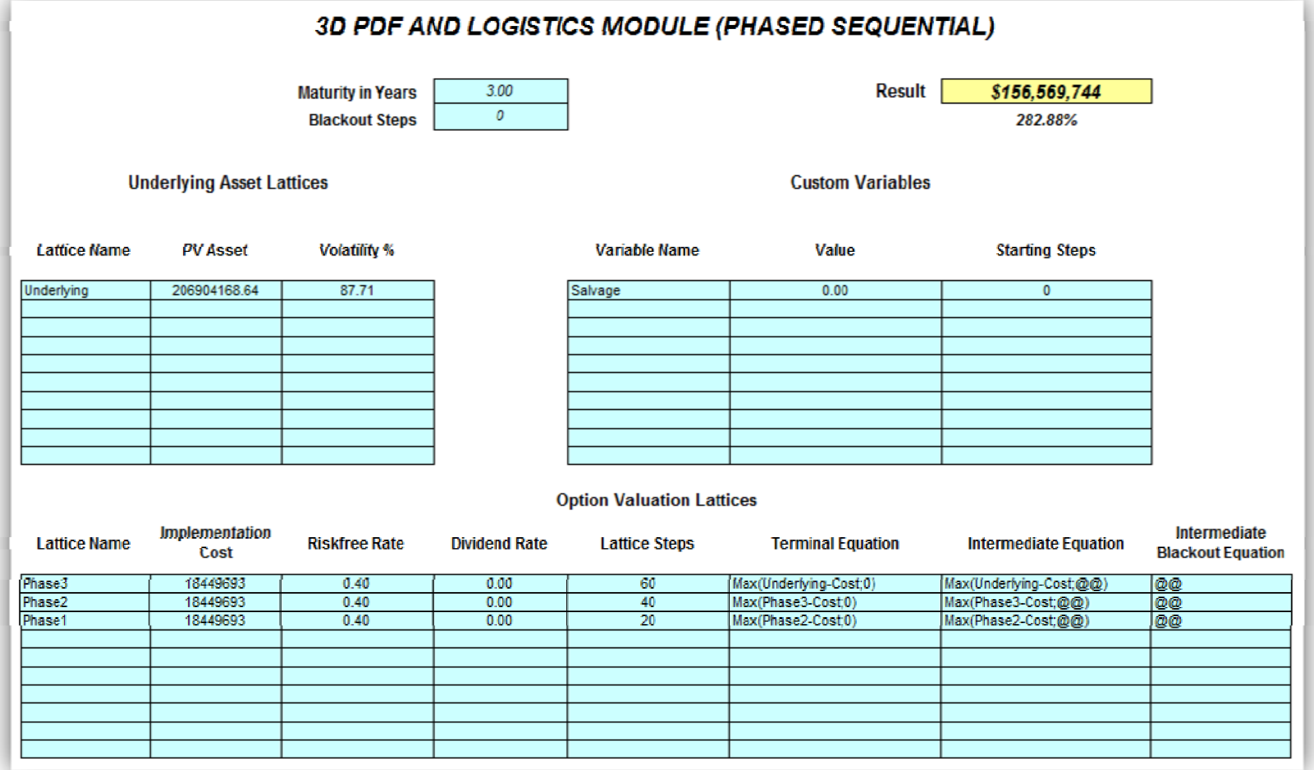
In addition, Figure 13 shows the Monte Carlo risk simulation results on the real options values. For instance, in comparing Options E and F, there is a 94% probability that Option E, which has a sequentially phased implementation of both 3D PDF and Logistics Module TC, provides a better return than Option F. In comparing Option E with Option B, there is a 95% confidence that, even with all the uncertainties in the collected data and risks of implementation success, including uncertainties of whether the estimated returns will materialize and so forth, there is at least a $1.27 million net advantage in going with Option E. Therefore, it is better to sequentially phase and stage-gate the implementation over several years, allow the ability to exit and abandon further stages if events unfold and uncertainties become resolved, so that further investment in the technology no longer makes sense.

As additional information, with KVA baseline of Option A, we see that without doing any implementations, there is still a 4.7% probability that staying As-Is returns negative ROIs, and even in the best case analysis there is less than a 5% probability that ROI for the base case will ever exceed 93%.

The final two charts in Figure 14 show that the risk simulated real options value has an expected value (mean) of $195 million with a corresponding average ROI of

363%. Finally, Figure 15 shows the comprehensive simulated risk statistics of the various option scenarios.

Figure 10. Strategic Real Options Implementation Pathways and Options



3D PDF AND LOGISTICS MODULE (PHASED SEQUENTIAL)

Maturity in Years: 3.00
Blackout Steps: 0
Result: $156,569,744
282.88%

Underlying Asset Lattices

Lattice Name	PV Asset	Volatility %
Underlying	206904168.64	87.71

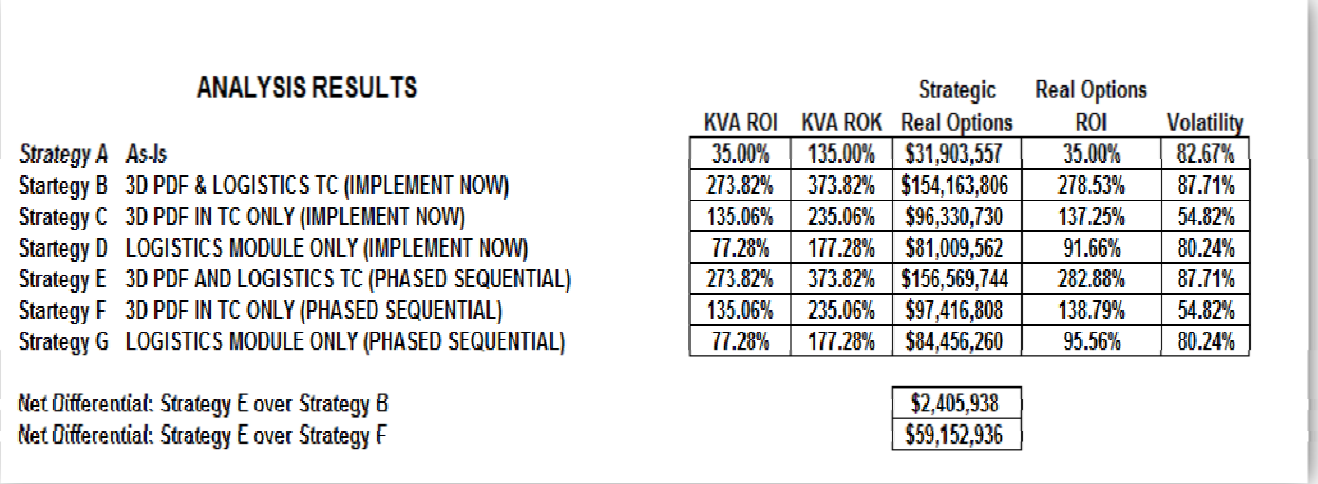
Custom Variables

Variable Name	Value	Starting Steps
Salvage	0.00	0

Option Valuation Lattices

Lattice Name	Implementation Cost	Riskfree Rate	Dividend Rate	Lattice Steps	Terminal Equation	Intermediate Equation	Intermediate Blackout Equation
Phase3	18449693	0.40	0.00	60	Max(Underlying-Cost;0)	Max(Underlying-Cost;@@)	@@
Phase2	18449693	0.40	0.00	40	Max(Phase3-Cost;0)	Max(Phase3-Cost;@@)	@@
Phase1	18449693	0.40	0.00	20	Max(Phase2-Cost;0)	Max(Phase2-Cost;@@)	@@

Figure 11. Sample Real Options Input Assumptions



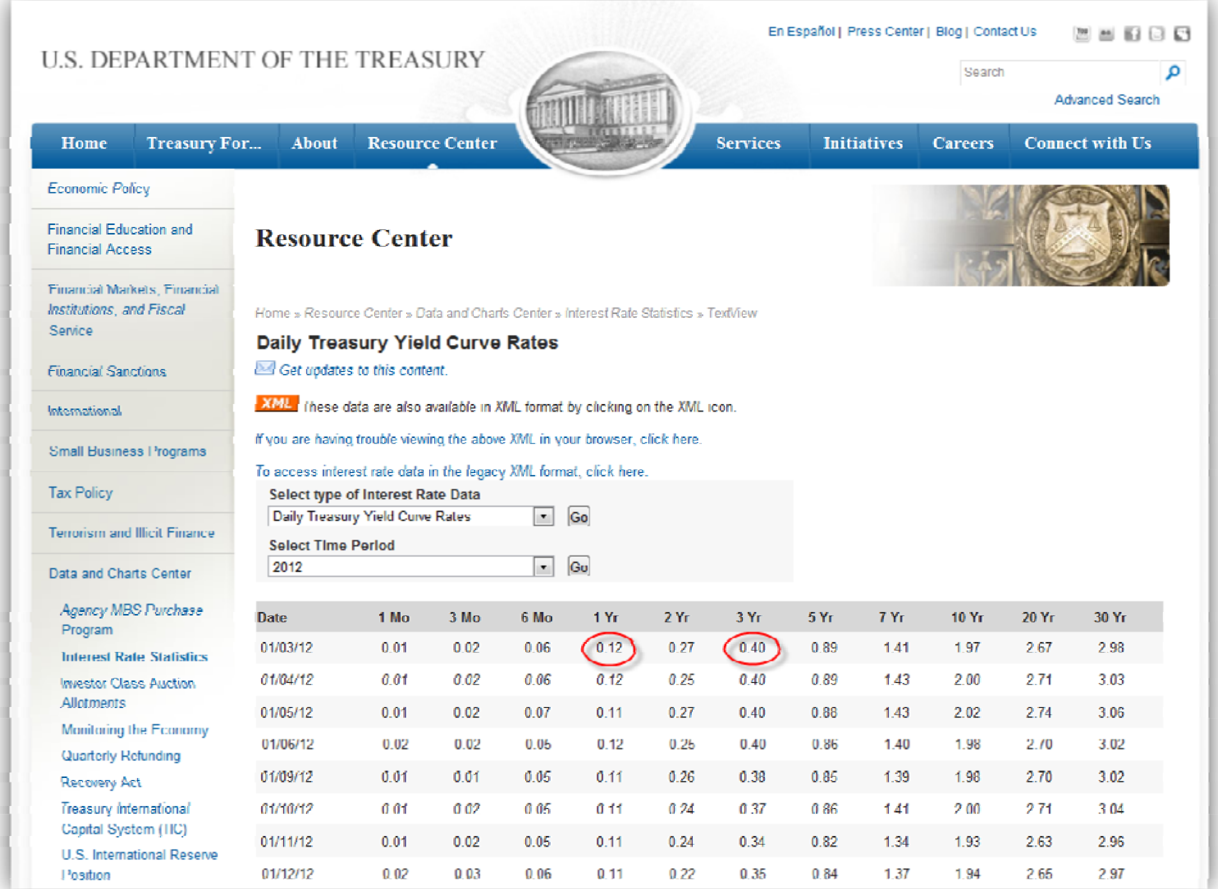
ANALYSIS RESULTS

		KVA ROI	KVA ROK	Strategic Real Options	Real Options ROI	Volatility
Strategy A	As-Is	35.00%	135.00%	$31,903,557	35.00%	82.67%
Startegy B	3D PDF & LOGISTICS TC (IMPLEMENT NOW)	273.82%	373.82%	$154,163,806	278.53%	87.71%
Strategy C	3D PDF IN TC ONLY (IMPLEMENT NOW)	135.06%	235.06%	$96,330,730	137.25%	54.82%
Startegy D	LOGISTICS MODULE ONLY (IMPLEMENT NOW)	77.28%	177.28%	$81,009,562	91.66%	80.24%
Strategy E	3D PDF AND LOGISTICS TC (PHASED SEQUENTIAL)	273.82%	373.82%	$156,569,744	282.88%	87.71%
Startegy F	3D PDF IN TC ONLY (PHASED SEQUENTIAL)	135.06%	235.06%	$97,416,808	138.79%	54.82%
Strategy G	LOGISTICS MODULE ONLY (PHASED SEQUENTIAL)	77.28%	177.28%	$84,456,260	95.56%	80.24%

Net Differential: Strategy E over Strategy B $2,405,938

Net Differential: Strategy E over Strategy F $59,152,936

Figure 12. Sample Real Options Values



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To access interest rate data in the legacy XML format, click here.

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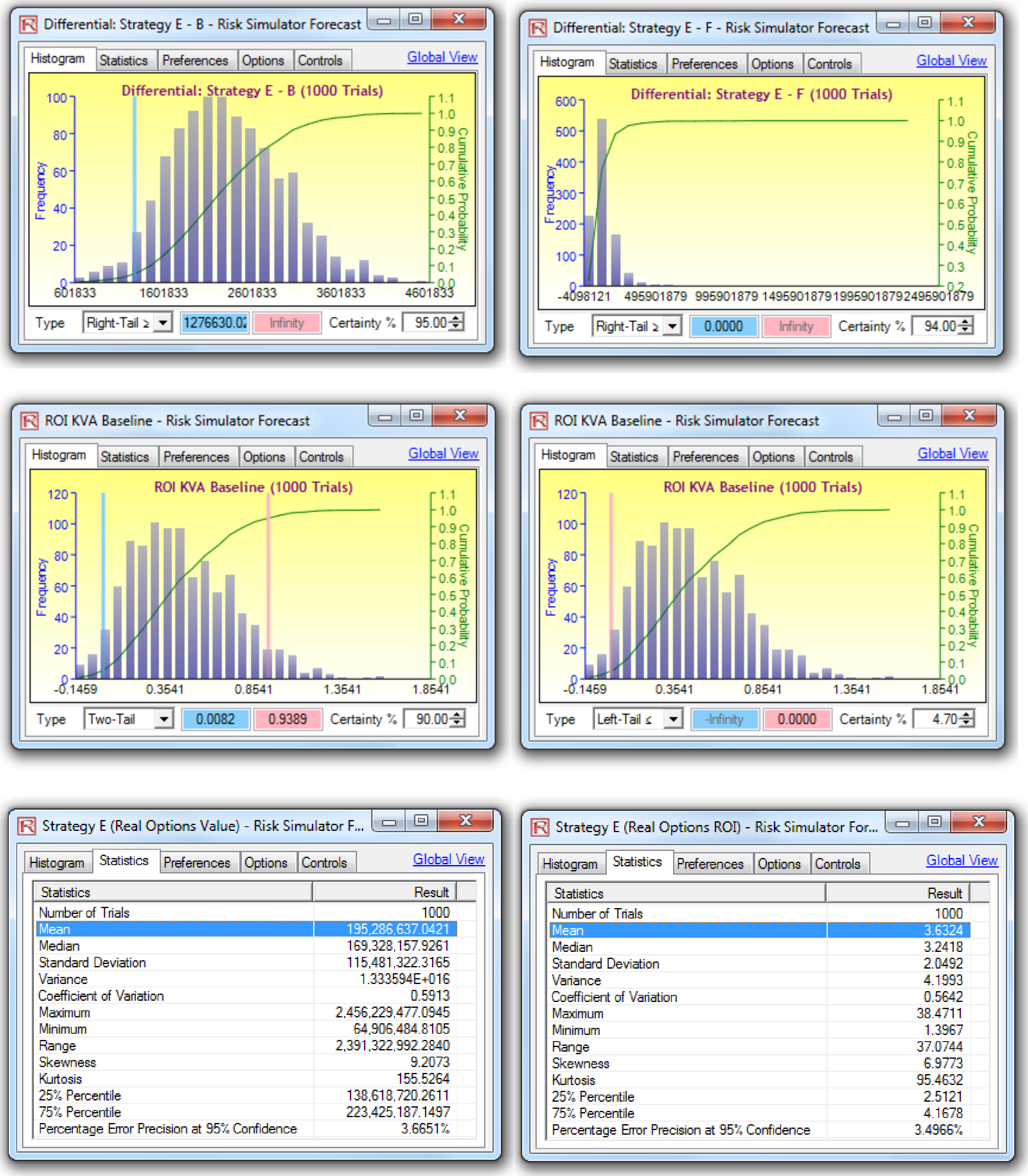
Select Time Period: 2012

Date	1 Mo	3 Mo	6 Mo	1 Yr	2 Yr	3 Yr	5 Yr	7 Yr	10 Yr	20 Yr	30 Yr
01/03/12	0.01	0.02	0.06	0.12	0.27	0.40	0.89	1.41	1.97	2.67	2.98
01/04/12	0.01	0.02	0.06	0.12	0.25	0.40	0.89	1.43	2.00	2.71	3.03
01/05/12	0.01	0.02	0.07	0.11	0.27	0.40	0.88	1.43	2.02	2.74	3.06
01/06/12	0.02	0.02	0.05	0.12	0.25	0.40	0.86	1.40	1.98	2.70	3.02
01/09/12	0.01	0.01	0.05	0.11	0.26	0.38	0.85	1.39	1.98	2.70	3.02
01/10/12	0.01	0.02	0.05	0.11	0.24	0.37	0.86	1.41	2.00	2.71	3.04
01/11/12	0.01	0.02	0.05	0.11	0.24	0.34	0.82	1.34	1.93	2.63	2.96
01/12/12	0.02	0.03	0.06	0.11	0.22	0.35	0.84	1.37	1.94	2.65	2.97

Figure 13. Risk-Free Rate



Type Right-Tail ≥ 1276630.0 Certainty % 95.00

Type Right-Tail ≥ 0.0000 Certainty % 94.00

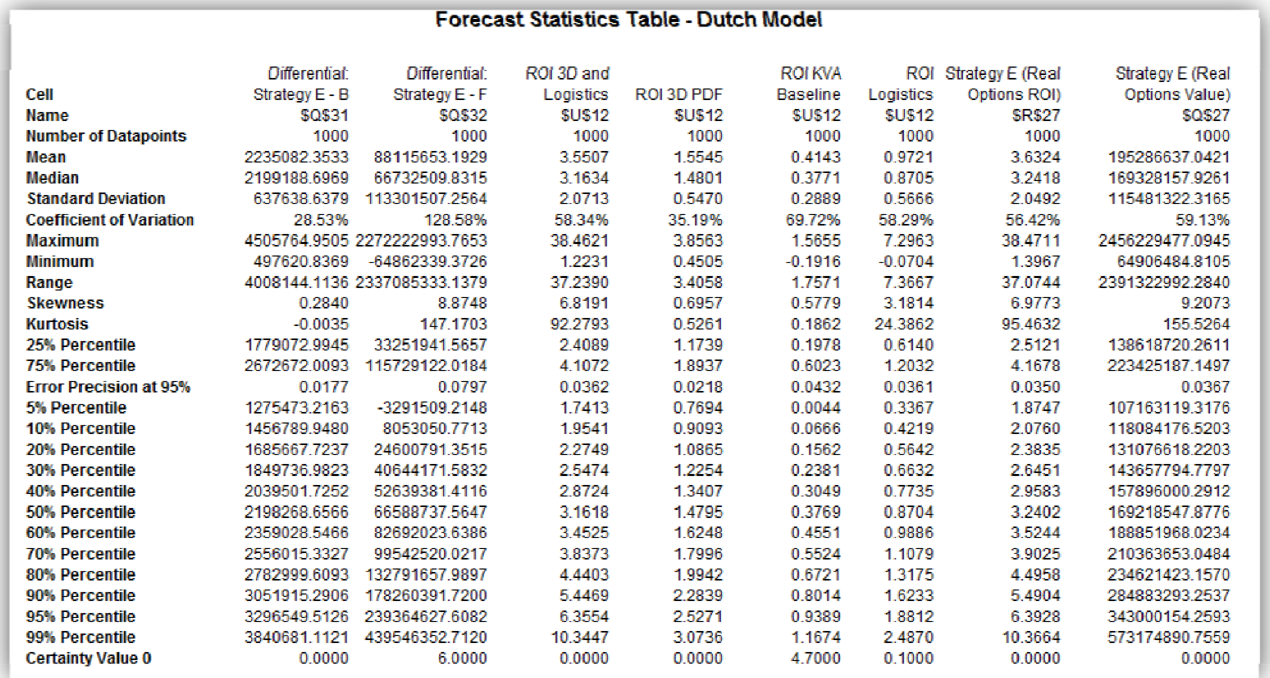
Type Two-Tail 0.0082 0.9389 Certainty % 90.00

Type Left-Tail ≤ 0.0000 Certainty % 4.70

Statistics	Result
Number of Trials	1000
Mean	195,286,637.0421
Median	169,328,157.9261
Standard Deviation	115,481,322.3165
Variance	1.333594E+016
Coefficient of Variation	0.5913
Maximum	2,456,229,477.0945
Minimum	64,906,484.8105
Range	2,391,322,992.2840
Skewness	9.2073
Kurtosis	155.5264
25% Percentile	138,618,720.2611
75% Percentile	223,425,187.1497
Percentage Error Precision at 95% Confidence	3.6651%

Statistics	Result
Number of Trials	1000
Mean	3.6324
Median	3.2418
Standard Deviation	2.0492
Variance	4.1993
Coefficient of Variation	0.5642
Maximum	38.4711
Minimum	1.3967
Range	37.0744
Skewness	6.9773
Kurtosis	95.4632
25% Percentile	2.5121
75% Percentile	4.1678
Percentage Error Precision at 95% Confidence	3.4966%

Figure 14. Risk Simulation Confidence and Percentiles



Forecast Statistics Table - Dutch Model

Cell	Differential: Strategy E - B	Differential: Strategy E - F	ROI 3D and Logistics	ROI 3D PDF	ROI KVA Baseline	ROI Logistics	Strategy E (Real Options ROI)	Strategy E (Real Options Value)
Name	Q31	Q32	U12	U12	U12	U12	R27	Q27
Number of Datapoints	1000	1000	1000	1000	1000	1000	1000	1000
Mean	2235082.3533	88115653.1929	3.5507	1.5545	0.4143	0.9721	3.6324	195286637.0421
Median	2199188.6969	66732509.8315	3.1634	1.4801	0.3771	0.8705	3.2418	169328157.9261
Standard Deviation	637638.6379	113301507.2564	2.0713	0.5470	0.2889	0.5666	2.0492	115481322.3165
Coefficient of Variation	28.53%	128.58%	58.34%	35.19%	69.72%	58.29%	56.42%	59.13%
Maximum	4505764.9505	2272222993.7653	38.4621	3.8563	1.5655	7.2963	38.4711	2456229477.0945
Minimum	497620.8369	-64862339.3726	1.2231	0.4505	-0.1916	-0.0704	1.3967	64906484.8105
Range	4008144.1136	2337085333.1379	37.2390	3.4058	1.7571	7.3667	37.0744	2391322992.2840
Skewness	0.2840	8.8748	6.8191	0.6957	0.5779	3.1814	6.9773	9.2073
Kurtosis	-0.0035	147.1703	92.2793	0.5261	0.1862	24.3862	95.4632	155.5264
25% Percentile	1779072.9945	33251941.5657	2.4089	1.1739	0.1978	0.6140	2.5121	138618720.2611
75% Percentile	2672672.0093	115729122.0184	4.1072	1.8937	0.6023	1.2032	4.1678	223425187.1497
Error Precision at 95%	0.0177	0.0797	0.0362	0.0218	0.0432	0.0361	0.0350	0.0367
5% Percentile	1275473.2163	-3291509.2148	1.7413	0.7694	0.0044	0.3367	1.8747	107163119.3176
10% Percentile	1456789.9480	8053050.7713	1.9541	0.9093	0.0666	0.4219	2.0760	118084176.5203
20% Percentile	1685667.7237	24600791.3515	2.2749	1.0865	0.1562	0.5642	2.3835	131076618.2203
30% Percentile	1849736.9823	40644171.5832	2.5474	1.2254	0.2381	0.6632	2.6451	143657794.7797
40% Percentile	2039501.7252	52639381.4116	2.8724	1.3407	0.3049	0.7735	2.9583	157896000.2912
50% Percentile	2198268.6566	66588737.5647	3.1618	1.4795	0.3769	0.8704	3.2402	169218547.8776
60% Percentile	2359028.5466	82692023.6386	3.4525	1.6248	0.4551	0.9886	3.5244	188851968.0234
70% Percentile	2556015.3327	99542520.0217	3.8373	1.7996	0.5524	1.1079	3.9025	210363653.0484
80% Percentile	2782999.6093	132791657.9897	4.4403	1.9942	0.6721	1.3175	4.4958	234621423.1570
90% Percentile	3051915.2906	178260391.7200	5.4469	2.2839	0.8014	1.6233	5.4904	284883293.2537
95% Percentile	3296549.5126	239364627.6082	6.3554	2.5271	0.9389	1.8812	6.3928	343000154.2593
99% Percentile	3840681.1121	439546352.7120	10.3447	3.0736	1.1674	2.4870	10.3664	573174890.7559
Certainty Value 0	0.0000	6.0000	0.0000	0.0000	4.7000	0.1000	0.0000	0.0000

Figure 15. Risk Simulation Statistics and Percentiles

A. Summary Results of the IRM Analysis

Integrated risk management and strategic real options methodologies were applied to the KVA-SD results and the results indicate that Option B had a value of $154.1 million (278% ROI) and Option E had a value of $156.5 million (282% ROI) where both options indicate that implementing 3D PDF and Logistics Module TC return the highest ROI and total strategic value, and both provide a significant value-add above and beyond Option A's As-Is condition with a value of $31.9 million (35% ROI). As Options B and E are most significant, we know that implementation of 3D PDF and Logistics Module TC return the highest value, and when implemented over time in a stage-gate process over several phases, would yield a slightly higher value (Option E exceeds Option B by about $2.4 million). Therefore, we conclude that 3D PDF and Logistics Module TC implemented in a phased stage-gate environment would yield the best results. In comparing Option E with Option B, there is a 95% probability, even with all the uncertainties in the collected data and risks of implementation success, as well as uncertainties of whether the estimated returns will materialize, there is a $1.27 million net advantage in going with Option E to sequentially phase and stage-gate the implementation over several years, and allow the ability to exit and abandon further stages if events unfold and uncertainties become resolved, so that further investment in the technology no longer makes sense.

IV. Conclusions

We collected new data on ship maintenance processes and the use and adoption of technologies in ship maintenance by the Royal Dutch Navy and Damen Shipbuilding. The data were used to build and calibrate a system dynamics model of Royal Dutch Naval ship maintenance. Model simulations of four technology adoption scenarios, reflecting the use of two available or developing technologies, generated estimates of maintenance operations behavior that were imported into knowledge value added models. The four technology adoption scenarios were then modeled in the KVA models. The KVA models estimated the returns on investment for individual processes and ship maintenance as a whole for each scenario. Results were analyzed to reveal the relative improvement provided by individual, and combinations of, technologies.

The results of this study, in combination with prior studies, make it evident that the technologies under review will make large contributions to cost reductions in ship maintenance processes. These conclusions are supported by the comparative analysis of the Dutch experience with similar supporting technologies. There appears to be no empirical evidence that would serve as an impediment to adopting the technologies in the near term rather than the longer term. We recommend an immediate adoption of the 3D LST and CPLM technologies to support ship maintenance processes.

A. Implications for Acquisition Practice

The current research has significant implications for acquisition practice. First, the conclusions support multiple previous investigations that recommend the adoption of available information technologies to reduce the costs of U.S. Navy ship maintenance. Second, multiple significantly different technologies (e.g., 3D LST, 3D PDF, logistics support) can improve ship maintenance operations. Third, among those studied, the expensive information technologies were found to benefit high-cost processes the most: for example, where labor can be replaced with technology. Doing so reduces costs and increases production rates by reducing cycle times. This implies that, if technology adoption efforts are to be prioritized, those with labor-intensive processes that can be replaced with technology should be given higher priority. The real options analysis of implementation strategies demonstrated that some technologies (3D PDF in this case) can dominate the value space and that phased implementation adds value compared to one-step implementation. The results of the current work recommend a careful investigation of available technologies and how they improve operations, followed by a phased development and implementation of the adoption of the chosen technologies.

B. Implications for Research

The results of the three KVA-based studies varied significantly. A likely cause is the difficulty in accurately forecasting, in quantitative terms, the impacts of new technologies on specific processes. The use of data and information from organizations that are actively developing and adopting information technologies (Damen) and performing operations similar to those performed by the U.S. Navy (Royal Dutch Navy) proved to be very valuable in improving the models (e.g., by adding the 3D PDF technology). Therefore, further refinement of the models should include actual application data, such as a study of actual technology adoptions by the U.S. Navy.

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Appendix A: Informants (Alphabetical Order) and Site Visit Locations

Informants

Sander Alles, Manager Maintenance & Spares, Damen Services, Gorinchem, The Netherlands.

Hein van Ameijden, Managing Director, Damen Schelde Naval Shipbuilding, Vlissingen, The Netherlands.

Nico de Vries, KTZT ir. Head of Corporate Planning and Strategy, Dutch Naval Maintenance and Service Agency, The Netherlands.

Bert Geisler, Business Development Director Shipbuilding, Siemens PLM Software, Hamburg, Germany.

Paul J. Kense, Advisor ILS, Naval Maintenance Establishment, Defense Materiel Organization, Royal Dutch Navy, Den Helder, The Netherlands.

Desmond Kramer, Manager, Integrated Logistic Support, Engineering Department, Damen Schelde Naval Shipbuilding, Vlissingen, The Netherlands.

Randy Langmead, Director, Marine/Federal Business Development, Siemens PLM Software, Washington, D.C.

Niek Marse, Integrated Logistic System, Engineering Department, Damen Schelde Naval Shipbuilding, Vlissingen, The Netherlands.

Michael Schwind, Vice President, Federal Sector, Siemens–UGS PLM Software, Philadelphia, PA.

Ronald van Noppen, KTZE ir. Head of Material and Logistics, Naval Maintenance and Service Agency, The Netherlands.

Frank Verhelst, Manager, Project Department, Damen Schelde Naval Shipbuilding, Vlissingen, The Netherlands.

Thijs Verwoerd, Project Manager, Damen Services, Gorinchem, The Netherlands.

Site Visit Locations

Damen Schelde Naval Shipbuiding (DSNS)
Glacisstraat 165
4381 SE Vlissingen, The Netherlands

Dutch Naval Maintenance Facilities
Nieuwe Haven
1780 CA Den Helder, The Netherlands

Damen Services
Industrieterrein Avelingen West 20
4202 MS Gorinchem, The Netherlands

Appendix B. Primer on Risk Simulation, Return on Investment, Strategic Real Options, and Portfolio Optimization—Integrated Risk Management[17]

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; however, 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

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[17] 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).

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 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 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 Accounting Office's (1997) "Assessing Risks and Returns: A Guide for Evaluating Federal Agencies' IT Investment Decision-Making" requires that IT investments apply ROI measures. DoD Directive 8115.01 (DoD, 2005) 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 (2006) implements policy and assigns responsibilities for the management of DoD IT investments as portfolios within the DoD enterprise where they define a portfolio to include outcome performance measures and an expected return on investment. The DoD Risk Management Guidance Defense Acquisition guidebook 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 complement these traditional techniques by pushing the envelope of analytics, but do not 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 A.1 and A.2 illustrate the errors in judgment when risks are ignored. Figure A.1 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).[18] Clearly, for the budget-constrained decision-maker, the cheaper the project, the better, resulting in the selection of Project X. The returns-driven 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?

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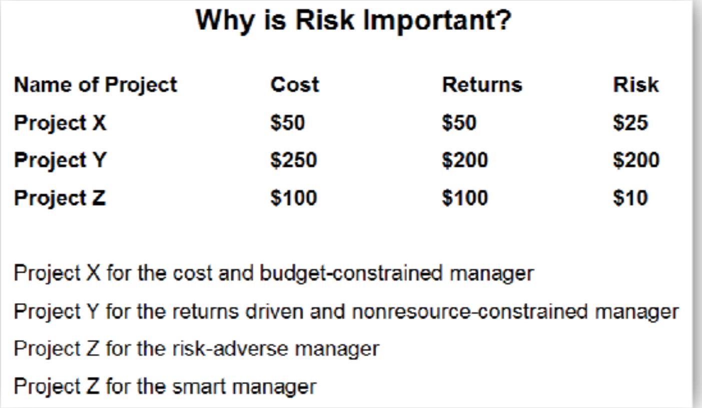
[18] Risks can be computed many ways, including volatility, standard deviation of lognormal returns, value at risk, and so forth. See *Modeling Risk*, by Johnathan Mun (Wiley, 2010) for more technical details.



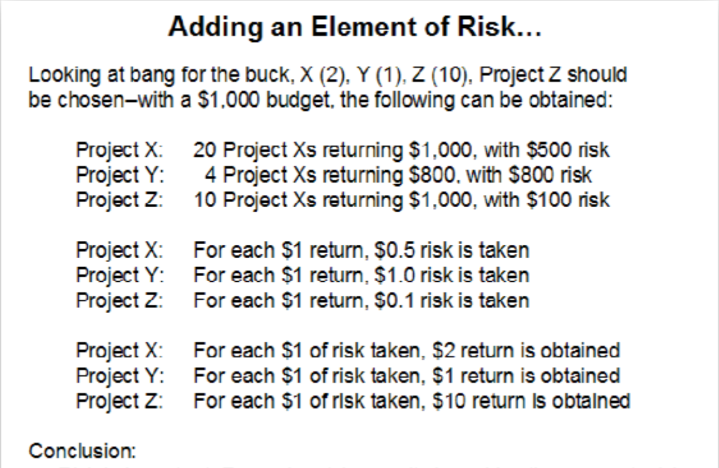
Why is Risk Important?

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 A.1. Why Is Risk Important?

Figure A.2 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 in risks, and so forth. It is clear from Figure A.2 that Project Z is the best project because 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 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 benefits or costs of $10 million each. Without risk analysis, a decision-maker should in theory be 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 A.2. 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 A.3 shows an example of a single-point estimate.[19] The estimated net revenue of $30 is simply that, a single point whose probability of occurrence is close to zero.[20] Even in the simple model shown in Figure A.3, 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

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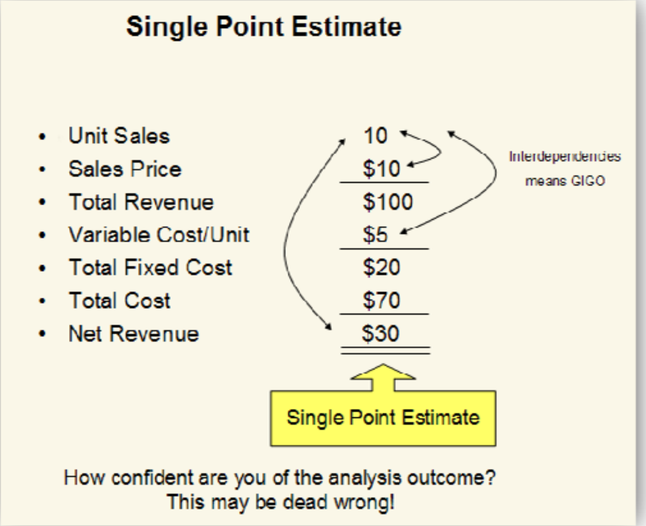
[19] We will demonstrate how KVA, combined with the traditional Market Comparables valuation method, allows for the monetization of benefits (i.e., revenue).

[20] 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 million 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%.

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 (Figure A.3), 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 actually be slightly lower to accommodate this increase in unit sales. Ignoring these interdependencies will reduce the accuracy of the model.



Single Point Estimate

Unit Sales	10
Sales Price	$10
Total Revenue	$100
Variable Cost/Unit	$5
Total Fixed Cost	$20
Total Cost	$70
Net Revenue	$30

Interdependencies means GIGO

Single Point Estimate

How confident are you of the analysis outcome?
This may be dead wrong!

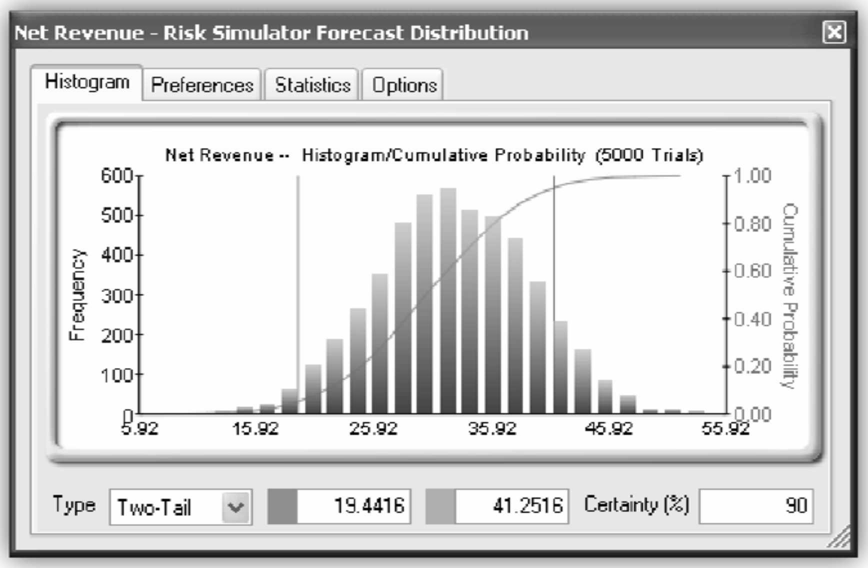
Figure A.3. Single-Point Estimates

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 (Figure A.3), 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 pre-specified 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 thousands of times while accounting for all the dynamic interactions between the simulated variables. The resulting net revenues from simulation, as seen in Figure A.4, 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, the 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.



Type: Two-Tail
19.4416
41.2516
Certainty (%): 90

Figure A.4. 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 by analyzing 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 a Knowledge Value Added (KVA) model, which will provide the required “benefits” or “revenue” proxy estimates to run an 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 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, and
- Relates outputs to the 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 the following:

- 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 & Housel, 2006; Pavlou, Housel, Rodgers, & Jansen, 2005; Housel & Kanevsky, 1995a).

Describing processes in common units also permits market comparable data to be generated, which is 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 in identifying how much value processes add. 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. 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. These data also provide 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 could still drive the straight route, but if you hit traffic, you could 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, to value and find the optimal strategic pathway to pursue, and to generate options to enhance the value of the project while managing risks. Sample options include the option to expand, contract, abandon, or sequentially 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 (Office of Budget Management [OMB], 2003), 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 versus 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.[21] 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

$$X_2 = Ie^{-q(T_2-t_1)}\Phi\left(\frac{\ln(I/X_1)+(r-q+\sigma^2/2)(T_2-t_1)}{\sigma\sqrt{(T_2-t_1)}}\right) - X_1e^{-r(T_2-t_1)}\Phi\left(\frac{\ln(I/X_1)+(r-q-\sigma^2/2)(T_2-t_1)}{\sigma\sqrt{(T_2-t_1)}}\right).$$

We then solve recursively for the value *I* and input it into the model:

$$\begin{aligned} Compound\ Option = {} & Se^{-qT_2}\Omega\left[\begin{array}{l}\dfrac{\ln(S/X_1)+(r-q+\sigma^2/2)T_2}{\sigma\sqrt{T_2}};\\ \dfrac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}};\sqrt{t_1/T_2}\end{array}\right] \\ & - X_1e^{-rT_2}\Omega\left[\begin{array}{l}\dfrac{\ln(S/X_1)+(r-q+\sigma^2/2)T_2}{\sigma\sqrt{T_2}}-\sigma\sqrt{T_2};\\ \dfrac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}}-\sigma\sqrt{t_1};\sqrt{t_1/T_2}\end{array}\right] \\ & - X_2e^{-rt_1}\Phi\left[\frac{\ln(S/I)+(r-q+\sigma^2/2)t_1}{\sigma\sqrt{t_1}}-\sigma\sqrt{t_1}\right]. \end{aligned}$$

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).

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[21] 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.

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.

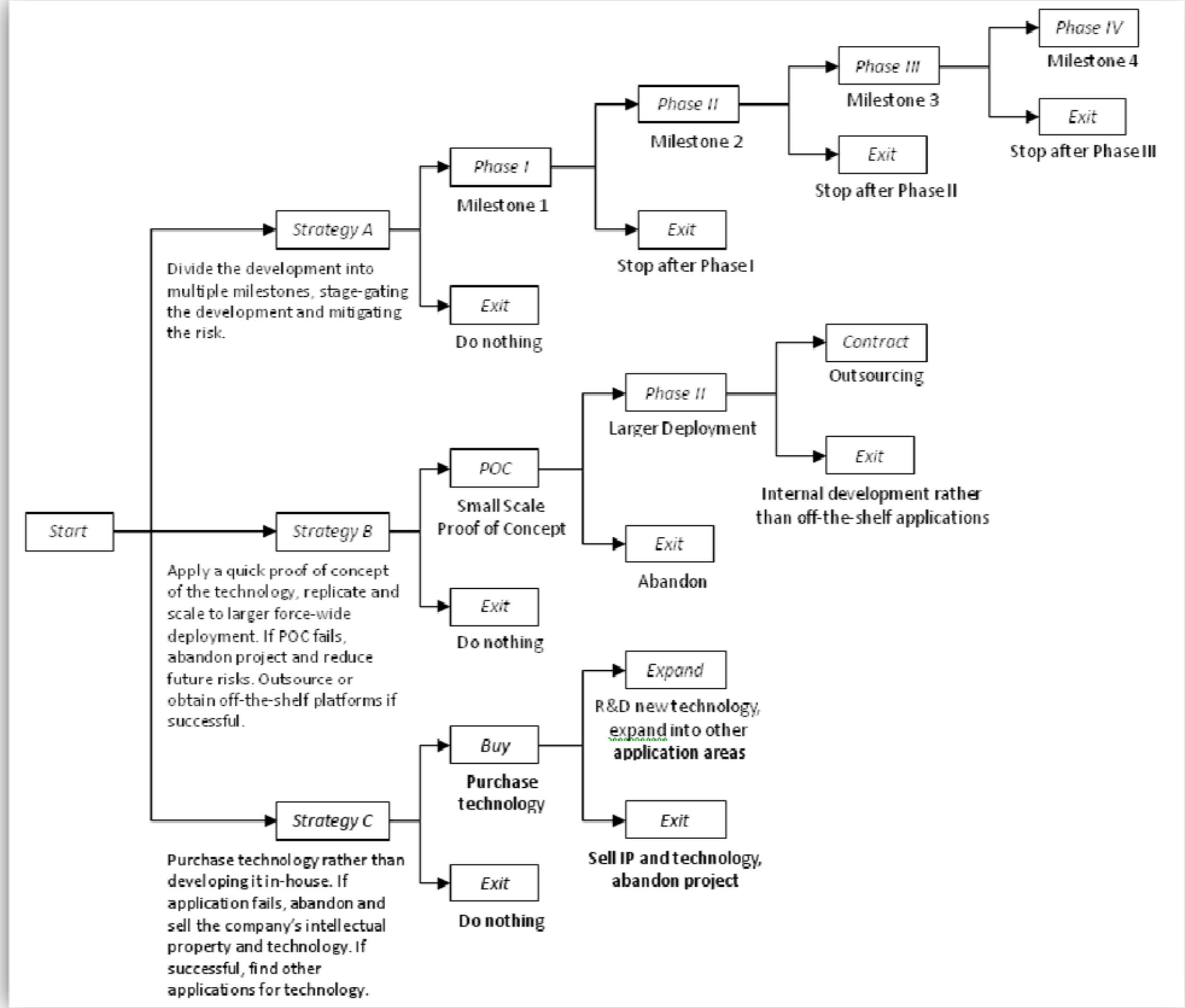

Figure A.5. Example of Real Options Framing

Figures A.6, A.7, and A.8 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 $10.2 billion) 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.[22] All the while, Monte Carlo simulation, real options, and forecasting methodologies are applied in the optimization model (e.g., each project's values shown in Figure A.6 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 exercise Project 1 without having to do Project 2, and so forth). The results are shown in Figure A.6.

Figure A.7 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 $3.8 billion was imposed? What if it was increased to $4.8 billion, $5.8 billion, and so forth? The efficient frontiers depicted in Figure A.7 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 A.8 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.

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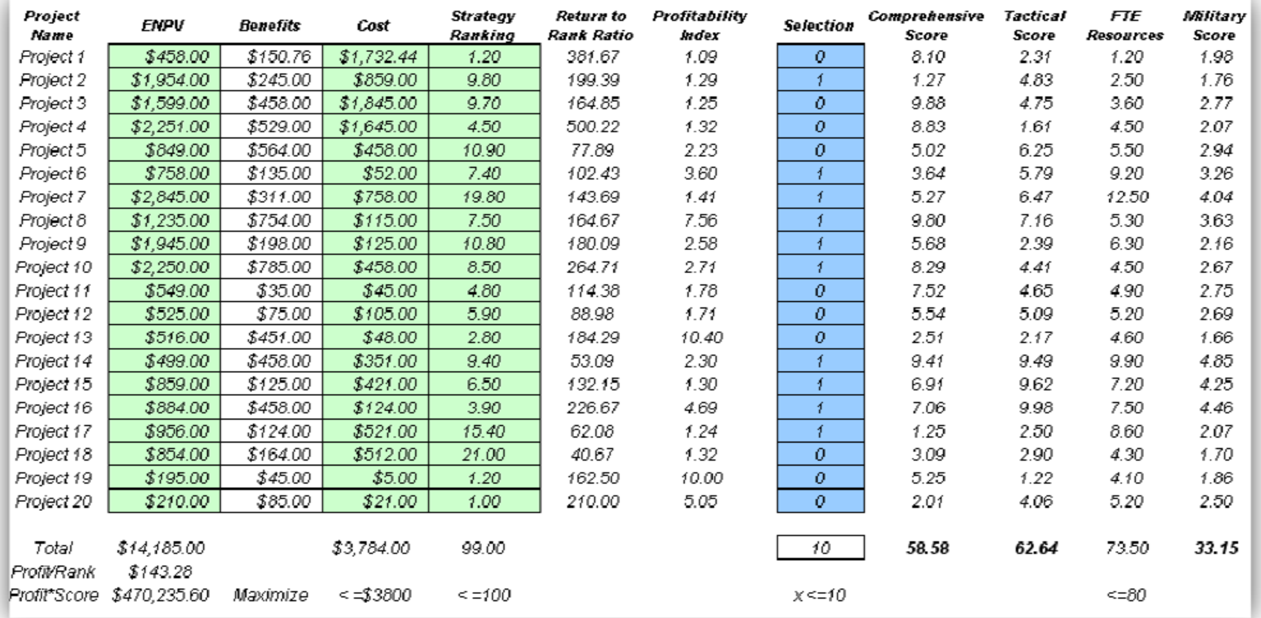
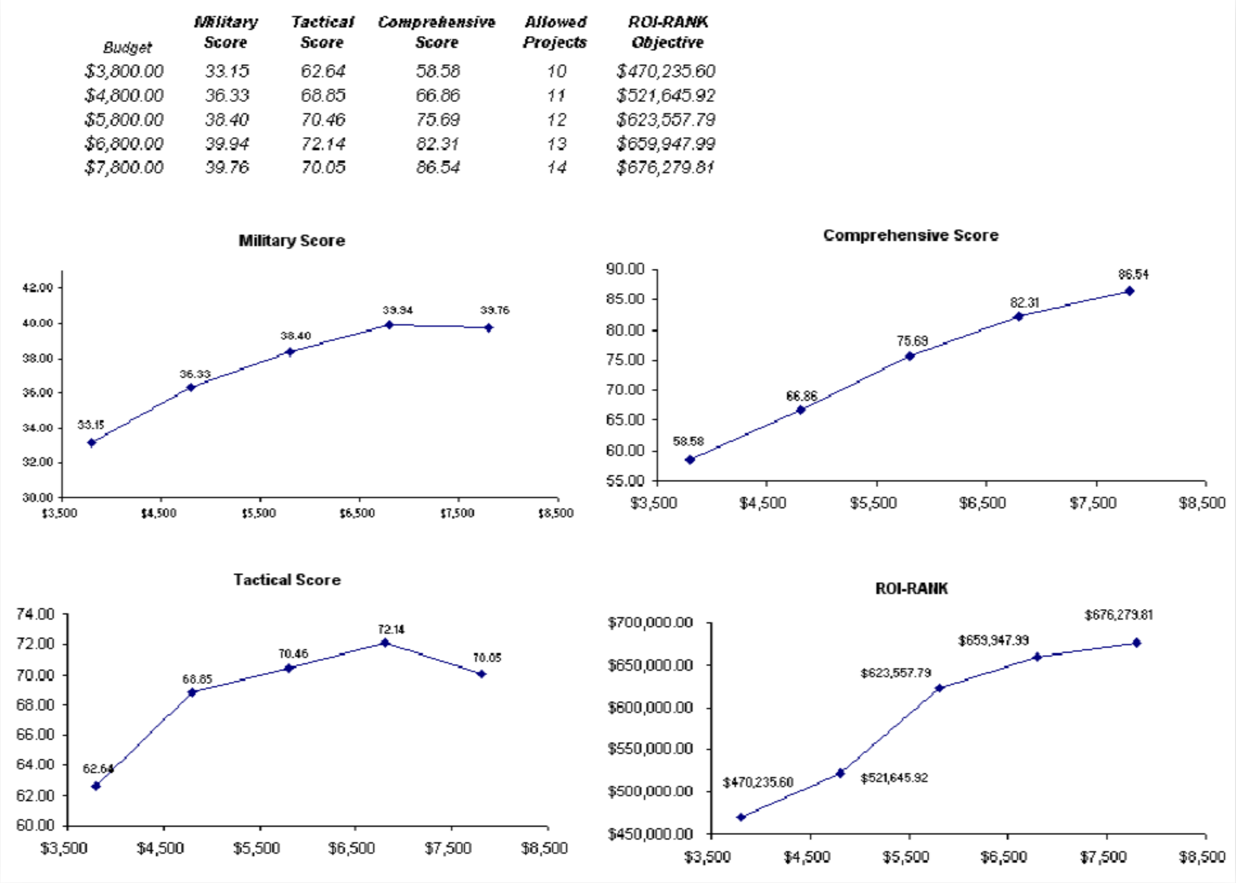
[22] There are 2 x 1018 possible permutations for this problem, and if tested by hand, the calculation would take years to complete. Using Risk Simulator, the problem is solved in about 5 seconds, or several minutes if Monte Carlo simulation and real options are incorporated in the analysis.



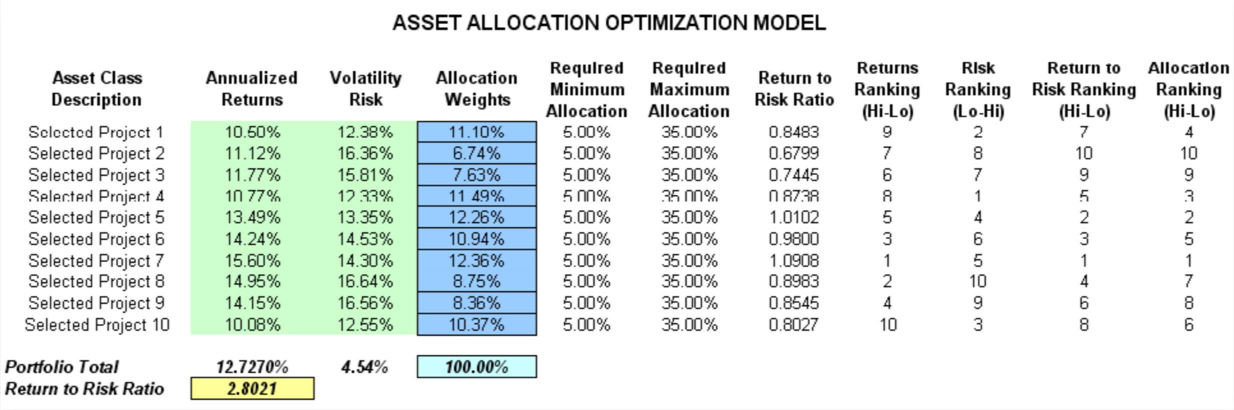
Project Name	ENPV	Benefits	Cost	Strategy Ranking	Return to Rank Ratio	Profitability Index	Selection	Comprehensive Score	Tactical Score	FTE Resources	Military Score
Project 1	$458.00	$150.76	$1,732.44	1.20	381.67	1.09	0	8.10	2.31	1.20	1.98
Project 2	$1,954.00	$245.00	$859.00	9.80	199.39	1.29	1	1.27	4.83	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 A.6. 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 A.7. 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 A.8. 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 for industry-specific problems. These phases can be performed either in isolation or together in sequence for a more robust integrated analysis.

Figure A.9 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).[23]

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[24]

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

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[23] 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.

[24] 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.

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 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[25]

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

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[25] 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.

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.

7. Portfolio and Resource Optimization[26]

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

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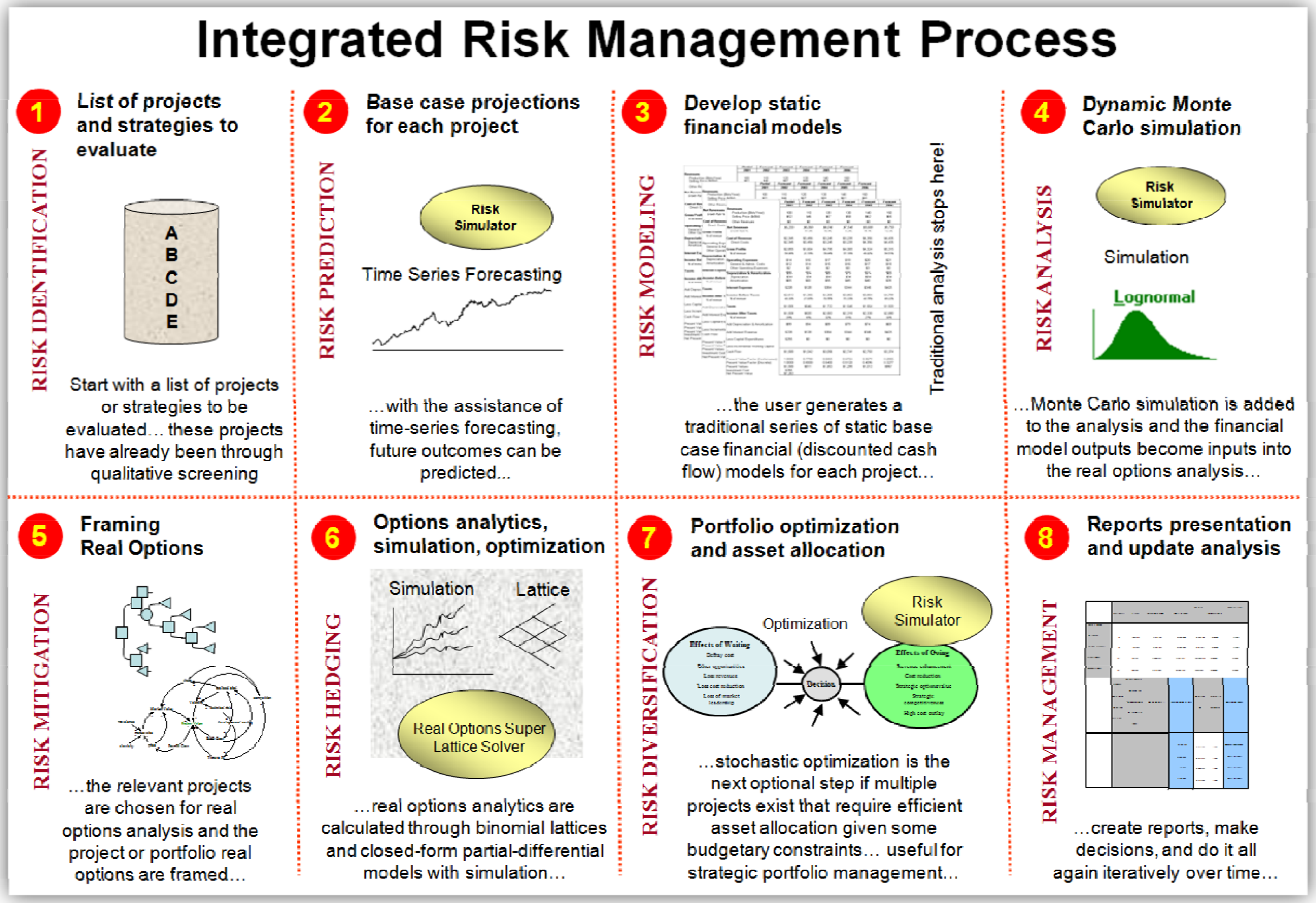
[26] See Chapters 10 and 11 of *Modeling Risk* (Wiley, 2006) by Dr. Johnathan Mun for details on using Risk Simulator to perform portfolio optimization.

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 have only 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 having 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 optimization 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 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 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.



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

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

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

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

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

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

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

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

Figure A.9. Integrated Risk Management Process

Conclusion

Hopefully it has now become evident that 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.[27] 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.

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[27] 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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