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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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Preface & Acknowledgements

Welcome to our Tenth Annual Acquisition Research Symposium! We regret that this year it will be a “paper only” event. The double whammy of sequestration and a continuing resolution, with the attendant restrictions on travel and conferences, created too much uncertainty to properly stage the event. We will miss the dialogue with our acquisition colleagues and the opportunity for all our researchers to present their work. However, we intend to simulate the symposium as best we can, and these *Proceedings* present an opportunity for the papers to be published just as if they had been delivered. In any case, we will have a rich store of papers to draw from for next year’s event scheduled for May 14–15, 2014!

Despite these temporary setbacks, our Acquisition Research Program (ARP) here at the Naval Postgraduate School (NPS) continues at a normal pace. Since the ARP’s founding in 2003, over 1,200 original research reports have been added to the acquisition body of knowledge. We continue to add to that library, located online at www.acquisitionresearch.net, at a rate of roughly 140 reports per year. This activity has engaged researchers at over 70 universities and other institutions, greatly enhancing the diversity of thought brought to bear on the business activities of the DoD.

We generate this level of activity in three ways. First, we solicit research topics from academia and other institutions through an annual Broad Agency Announcement, sponsored by the USD(AT&L). Second, we issue an annual internal call for proposals to seek NPS faculty research supporting the interests of our program sponsors. Finally, we serve as a “broker” to market specific research topics identified by our sponsors to NPS graduate students. This three-pronged approach provides for a rich and broad diversity of scholarly rigor mixed with a good blend of practitioner experience in the field of acquisition. We are grateful to those of you who have contributed to our research program in the past and encourage your future participation.

Unfortunately, what will be missing this year is the active participation and networking that has been the hallmark of previous symposia. By purposely limiting attendance to 350 people, we encourage just that. This forum remains unique in its effort to bring scholars and practitioners together around acquisition research that is both relevant in application and rigorous in method. It provides the opportunity to interact with many top DoD acquisition officials and acquisition researchers. We encourage dialogue both in the formal panel sessions and in the many opportunities we make available at meals, breaks, and the day-ending socials. Many of our researchers use these occasions to establish new teaming arrangements for future research work. Despite the fact that we will not be gathered together to reap the above-listed benefits, the ARP will endeavor to stimulate this dialogue through various means throughout the year as we interact with our researchers and DoD officials.

Affordability remains a major focus in the DoD acquisition world and will no doubt get even more attention as the sequestration outcomes unfold. It is a central tenet of the DoD’s Better Buying Power initiatives, which continue to evolve as the DoD finds which of them work and which do not. This suggests that research with a focus on affordability will be of great interest to the DoD leadership in the year to come. Whether you’re a practitioner or scholar, we invite you to participate in that research.

We gratefully acknowledge the ongoing support and leadership of our sponsors, whose foresight and vision have assured the continuing success of the ARP:

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Acquisition Management

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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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Abstract

Initiatives to reduce ship maintenance costs 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. This research collected data on Dutch ship maintenance operations and used it to build three types of computer simulation models of ship maintenance and technology adoption. Results were 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. 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.

Introduction

The current cost-constrained environment within the federal government and the 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.

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, three-dimensional laser scanning technology (3D LST) and collaborative product life-cycle 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 savings. 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 (RDN) 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.

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 the comparison of those data with previous U.S. Navy results were critical steps 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 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?

Research Methodology and Background[1]

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. The knowledge value added (KVA) methodology (Housel & Kanevsky, 1995) 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. 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.

The system dynamics methodology was used to model the impacts of automation on operations. System dynamics 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. Forrester (1961) developed the methodology's philosophy, and Sterman (2000) specified the modeling process with examples and described numerous applications. System dynamics is used to build causal-based (versus 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

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[1] See Ford, Housel, and Mun (2012) for a more detailed description of the research methodologies applied.

the performance of many types of systems, including development projects. 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.

The integrated risk management (IRM) framework and supporting toolset was used to optimize the portfolio over time. 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).

The research team collected data on Dutch ship operations as described in the section titled Data Collection Methods and used it to build three types of computer simulation models of ship maintenance and technology adoption: KVA models of return on technology investments in those operations, system dynamics models (SD) of ship maintenance operations, and IRM 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.

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 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 with officers and civilian employees of the RDN, and (2) tours of three Dutch shipbuilding and maintenance facilities.

In-person interviews and meetings with managers at Damen and with officers and a civilian employee of the RDN 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 RDN in three locations over three days. 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 (ILS), and information technology products under development for use in ship maintenance.[2] Separately, a meeting and semi-structured interview was conducted with

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[2] Copies of these 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.

the two RDN officers responsible for ship maintenance at the RDN shipyard at Nieuwe Haven in Den Helder. Tours of the RDN fleet maintenance facility in Nieuwe Haven and two Damen shipyards were provided during the data collection trip.

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 people and builds an average of 150 vessels per year. The firm obtained Damen Schelde in 2000, which focuses exclusively on naval ship design, building, and maintenance. 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 RDN.

Damen Schelde has used an 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; quality assurance, quality control (QAQC); 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 its design and manufacturing. Of particular relevance to the current work, Damen Schelde uses four separate software products to manage its shipbuilding: an advanced three-dimensional CADD program for design, a CPLM product as a database for ship components, 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 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).
2. 3D PDF files: Three-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., an 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 or 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[3]), and other information that is difficult or impossible to show with traditional, static, two-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.[4]
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 the duration for getting information into Damen databases (e.g., 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, spare parts packages, and maintenance management systems. It also provides information technology support for Damen. It is 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

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[3] *Line replaceable unit* is a commonly used term in manufactured devices for any modular component that is designed to be interchangeable.

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

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 (e.g., the frequency orders for specific components) captured through this system 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.

Royal Dutch Navy 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 legacy information systems to an integrated ERP system for maintenance operations. Also, 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 it 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 its ship designs.

The primary informant on RDN fleet maintenance operations provided a diagram of those operations (see Figure 1) and a written description of each of the steps identified in the diagram.

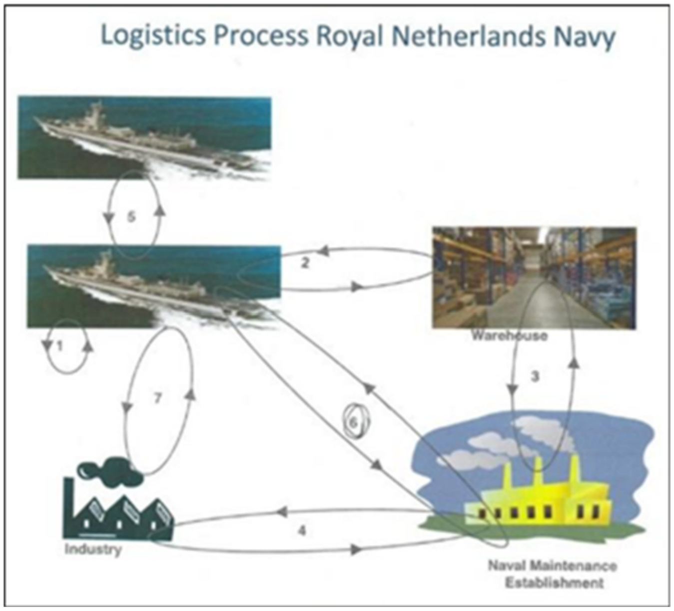

Figure 1. **Diagram of Royal Dutch Navy Fleet Maintenance Processes**
(P. Kense, personal communication, June 21, 2012)

The process steps shown in Figure 1 were described in writing by the informant with the following list.[5] 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.

Logistic Process Royal Netherlands Navy

1. In case LRU fails the on-board personnel will replace this LRU by a spare (on-board; OLM qualification required).
2. The defect LRU will be send to the warehouse, and a “new” LRU will be send to the ship.
3. 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).
4. 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.
5. If spare is not available, sometimes it will be cannibalized from another ship.
6. 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).
7. If the problem is too complex for the NME also, the industry can be hired to solve this problem.

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

The following seven process steps were elaborated on by the informant (the abbreviations *DLM*, *OLM*, and *ILM* refer to Dutch terms for training levels):

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

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

System Dynamics Model Structure

The system dynamics model simulates the movement of LRU among the various locations where they are used, stored, or repaired. Each flow of LRUs between two stocks represents the processing rate of one of the process steps in a KVA model. A simplified diagram of the stocks and flows of the model are shown in Figure 2. Boxes represent stocks, or accumulations of LRU. Each stock in Figure 2 represents a location in Figure 1, plus on-board LRU storage as a separate LRU accumulation. Arrows with valve symbols in Figure 2 represent the movement of LRUs between stocks. Numbers in parentheses in the titles of flows represent the process steps shown in Figure 1 (ovals with arrows) and the KVA model process steps (described later).

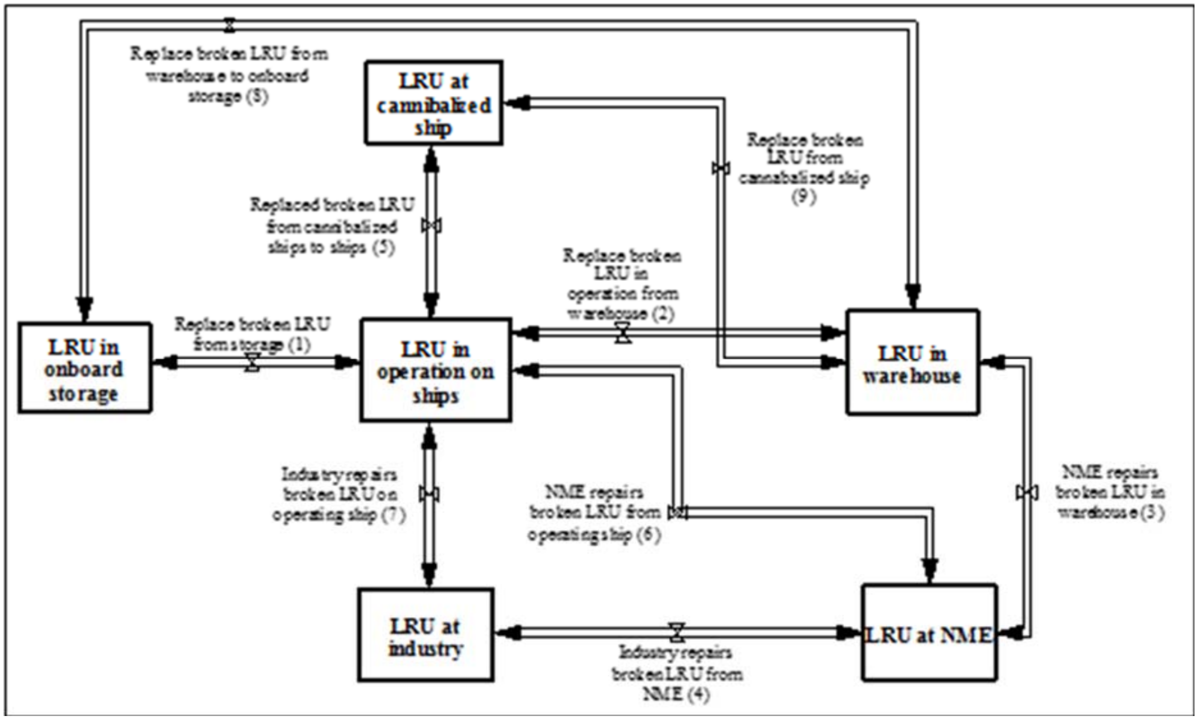


Figure 2. Royal Dutch Navy Ship Maintenance: Stocks and Flows of the System Dynamics Model

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 the left of Figure 2) 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 the top in Figure 2). 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 the right in Figure 2). 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 (see Ford, Housel, & Mun, 2012, for details).

Knowledge Value Added Models to the Royal Dutch Navy Ship Maintenance

Four KVA models were built based on the RDN ship maintenance processes (see Ford, Housel, & Dillard, 2010, for details and examples of KVA modeling):

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
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

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 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 are shown in Table 1.

Table 1. 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 1, 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.

Analysis of Simulation Model Results

A variance analysis was performed on the KVA model results (Table 1) to evaluate the relative impacts of the adoption of different technologies (Table 2). ROIs for each of the three technology adoption alternatives were compared with the baseline ROIs to estimate improvement due to technologies (see the left three columns of results in Table 2). In addition, the improvement from adopting both technologies over adopting only the 3D PDF technology was estimated (see the right column in Table 2).

Table 2. Variance Analysis of Knowledge Value Added 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 2, adding either or both of the technologies improves overall ship maintenance ROI, as indicated by the positive numbers in the last row of Table 2. 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 (see the lower right result in Table 2).

Adopting the technologies does not impact the ROI of individual processes equally. Among the seven core processes (1–7), adding only a logistics package (see the left column of results in Table 2) 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%.

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 LST and CPLM tools into the SHIPMAIN program. Komoroski (2005) investigated the early phases of SHIPMAIN (see Table 3). Adding the 3D LST and CPLM technologies improves the overall preparation for maintenance process ROI. Adding these technologies generally improves individual processes as well. The range of improvements across individual processes is large, varying from 0% (Issue Tasking) to 3,031% (Generate Drawings). Cost reduction explains these differences. For example, the adoption of technology in Core Processes 4 (Conduct Shipcheck) and 7 (Generate Drawings) would 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 (see Table 3). Adding the technologies also improves overall maintenance implementation process ROI. Adding these technologies also improves each of the individual processes. 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 (see Seaman, Housel, & Mun, 2007, for details).

Table 3. 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 ROIs after technology adoption 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 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, 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 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, in which 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 for 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.

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.

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 was some uncertainty in the estimates provided by the subject-matter experts, application of the appropriate statistical distributions of input was 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 (U.S. Air Force, 2007) 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 were inserted into the three main variables: percentage automation, time process is executed, and average time to complete. A risk simulation of 10,000–1,000,000 simulation trials was run to obtain the results.

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 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?

Integrated Risk Management: Framing the Real Options

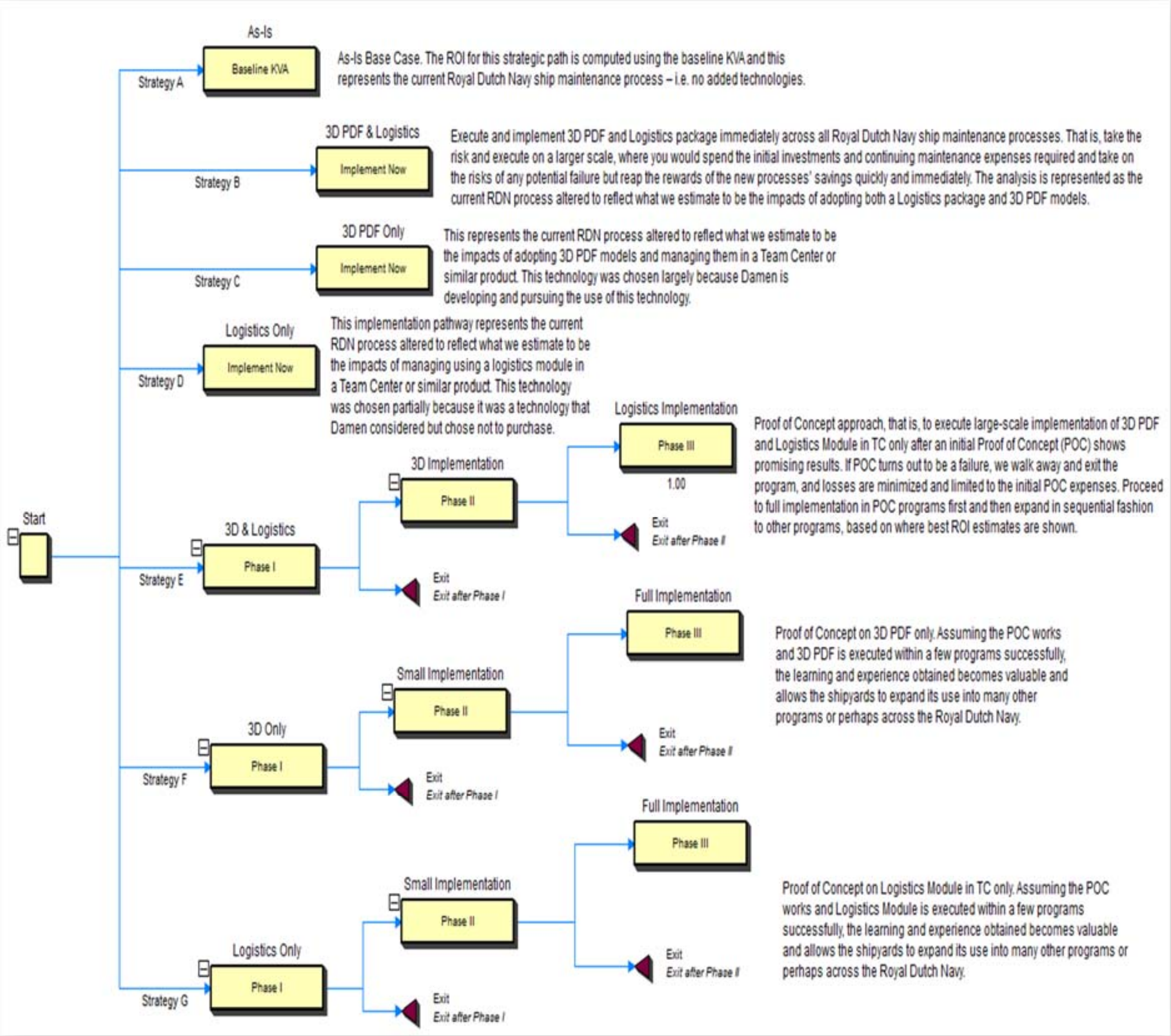
As part of the first round of analysis, Figure 3 illustrates some of the potential implementation paths for 3D PDF/Logistics TC. Clearly, some of the pathways and flexibility strategies can be refined and updated through the passage of time, actions, and events. With the evolution of the implementation, 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 RDN ship maintenance process (i.e., no newly added technologies).
- Option B: Execute and implement 3D PDF and Logistics package immediately across all RDN 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 (POC) approach. That is, to execute large-scale implementation of 3D PDF and Logistics Module in TC only after an initial 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: POC 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 RDN.
- Option G: POC 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 RDN.



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 added technologies.

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.

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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.

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.

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 shipyards to expand its use into many other programs or perhaps across the Royal Dutch Navy.

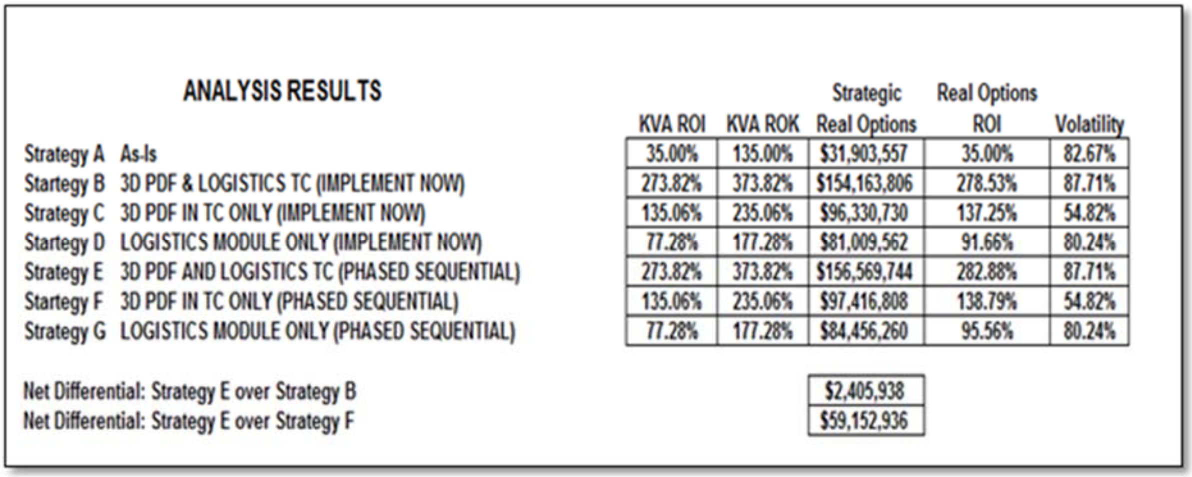
Proof of Concept on Logistics Module in TC only. Assuming the POC works and Logistics Module is executed within a few programs successfully, the learning and experience obtained becomes valuable and allows the shipyards to expand its use into many other programs or perhaps across the Royal Dutch Navy.

Figure 3. Sample Real Options Values

Integrated Risk Management: Strategic Flexibility Real Options Results

Figure 4 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, the Monte Carlo risk simulation results on the real options values were developed (but are not shown here for brevity; see Ford, Housel, & Mun, 2012). 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 Options E and 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, allowing 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. The risk-simulated real options value has an expected value (mean) of $195 million, with a corresponding average ROI of 363%.



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 4. Sample Real Options Values

Summary Results of the Integrated Risk Management Analysis

IRM 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 returns 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 Options E and B, there is a 95% probability, even with all the uncertainties in the collected data and risks of implementation success as well as the uncertainties of whether the estimated returns will materialize, that there is a $1.27 million net advantage in going with Option E to sequentially phase and stage-gate the implementation over several years, allowing 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.

Conclusions

We collected new data on ship maintenance processes and the use and adoption of technologies in ship maintenance by the RDN and Damen Shipbuilding. The data were used to build and calibrate a system dynamics model of RDN 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 KVA models. The four technology adoption scenarios were then modeled in the KVA models. The KVA models estimated the ROIs 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.

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, such as 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.

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 (RDN) 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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