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PROJECT-RISK MANAGEMENT AND DECISION ANALYSIS IN MARITIME MAINTENANCE AND REPAIR

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Abstract
The purpose of this paper is to provide insights regarding the implementation of using Project Risk Management (PRM) and Decision Analysis (DA) in managing projects for complex systems such as maritime vessels. The PRM approach apprehends many forms of risk both internal and external within a given project and assists the manager in determining the level of importance of each individual project phase and component to optimize project success. Ship Maintenance and Repair project decision-making requires that risk management and risk analysis techniques be applied in order to guide management in making better decisions to meet ship service life perspective. The Life Cycle Assessment (LCA) approach to project management is used to identify the short term limitations of projects with respect to a product's life cycle. There are many tools and techniques to assist project managers in implementing optimal solutions, but published statistics indicate failures to meet schedules and/or budgets are still common. The methodology for reducing risk and for determining how much contingency to add to reduce residual risk to an acceptable level will be discussed herein. This paper contributes to a discussion of empirical investigation centered across the areas of Project Management, Decision-Making, Reliability Centered Maintenance and Condition-Based Management.

Introduction
The inspection, repair, and maintenance of maritime vessels is an exceedingly expensive and complex system of interrelated operations with time sensitive availability imperatives. The rapid growth of complex systems on maritime vessels, coupled with extensive system interoperability requirements make each vessel a "system of systems," and part of a fleet of vessels and land-based organizational logistic systems.

This article focuses on using Project Risk Management (PRM) and Decision Analysis (DA) in managing projects for complex systems such as vessel repair and maintenance. The PRM approach realizes many forms of risk both without and within a given project and assists the manager in determining the level importance of each individual project phase and component to optimize project success. The life cycle approach to project management is used with short term repair and maintenance work items of several years with respect to a product's service life and life cycle.

Importance of Ship Repair and Maintenance. The mission of any maritime organization, whether commercial or governmental, is to develop, deliver and maximize vessel availability at a reduced cost while meeting scheduled operational commitments. The importance of this industry is not only economic, but critical to national security. There is a viable industrial expertise in shipbuilding, repair, and maintenance on a world-wide basis, but the assurance of maintaining a vessel's availability to meet operational commitments may always be fortuitous. This is troublesome for governments and commercial shipping companies.

The Naval Sea Systems Command (NAVSEA) sole purpose is the execution of directives and fulfillment of mission imperatives to enable the Navy to carry out the defense of the United States of America. To accomplish this endeavor, NAVSEA manages 150 acquisition programs and manages foreign military sales cases that include billions of dollars annually in military sales to partner nations. The NAVSEA organization has 33 activities in 16 states, with a force of 53,000 civilian, military and contract support personnel, NAVSEA engineers, builds, buys and maintains the Navy's ships and submarines and their combat systems (Hynes, et al., 2002).

The current trend of NAVSEA's efforts is to reduce costs, maximize resources, and improve efficiencies in the shipbuilding, repair, and maintenance of vessels. This trend is well within the area of engineering management and decision sciences, utilizing multi-objective tradeoff analyses. The project management aspect of ship repair and maintenance for any naval vessel may appear simple, but is actually quite complex when one looks at the many systems and interrelated sub-systems that must be maintained in top condition. Additionally, the project managers from several

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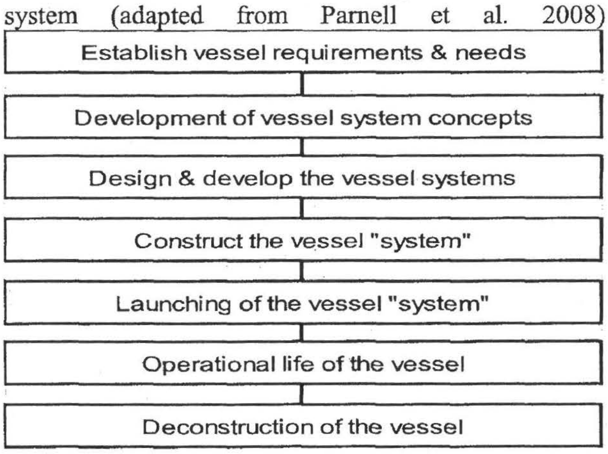
organizations and commands, each with specific perspectives, must also consider the vessel's role in the squadron (e.g. cruiser-destroyer group) and the fleet of naval vessels. Each ship is also "competing" for limited resources - the most common concerns of defense analysts are cost, schedule, industrial base capacity, shipyard performance, and program management strategies (Arena, Schank, & Abbott, 2004). Furthermore existing tools "lacked an integrated approach that would allow analysts to consider not just individual elements (e. g., manpower and procurement funding requirements) but the interaction and interrelationships among the industrial base components – from attrition rates to ship life extensions, from labor learning curves to overhead costs" (Arena, et al., 2004).

Parnell et al (2008) used system life cycle to describe NAVSEA's decision process in vessel systems, from inception to removal from service and disposal (Parnell, Driscoll, & Henderson, 2008). See Exhibit 1. This research is focused on the operational vessel service life of 35 years.

Exhibit 1. NAVSEA's decision process in vessel system (adapted from Parnell et al. 2008)



On the other hand, commercial steam ship companies have similar organizational imperatives, but with far fewer staffing and have an increased reliance on ship yard expertise. Additionally, commercial vessels are not as sophisticated with the myriad of systems and personnel on naval vessels which may lead to understand their maintenance strategy.

Project Risk Management. "Risk is a major factor in the management of projects because of their one-time nature and the uniqueness of the deliverables" (Shtub, 2005). Project managers have obligation, working with teams, to " identify and evaluate potential risks; derive a response strategy and action plans to contain the risks, implement the actions and monitor the results, and promptly resolve any issues arising from risks that happen" (Young, 2004) Hornjak (2001). indicated there were several methods to manage risky situations using a crisis management methodology, which include: (1) belt-and-suspenders approach, or have sufficient insurance to be immunized from problems; (2) pin-the-blame approach, or blame someone else directly or indirectly involved in the problem now a crisis; (3) the tombstone approach, which is to have total disregard for potentially disastrous consequences of inaction and do nothing; and (4) slash-and-burn approach, which involves outsiders waiting in the wings to "turn around" or dismember a company (Hornjak, 2001).

Life Cycle. The description of a life-cycle includes the products original inception or design, its service life, and to include its final "resting place" as a discarded product. MIL-STD-882 applies to all aspects of DoD procurement items, systems, and materials and defines life cycle as: "all phases of the systems life cycle including design, research, development, test and evaluation, production, deployment (inventory), operations and support, and disposal" (*DoD MIL-STD-882D Standard Practice for System Safety*, 2000). Life cycle cost (LCC) as defined by the Navy, includes follow-up ship acquisition cost, life cycle fuel cost, and life cycle manning cost. Annual life cycle costs are discounted to the base year, using an annual discount rate of 7%. Historical shipbuilding costs are inflated to the base year using a 5% average annual inflation rate from 1981 data. Producibility is also considered in the construction cost equations. Producibility factors are based on hull form characteristics, machinery room volume, and deck height" (Brown & Salcedo, 2003). Defense Systems Total Ownership Cost (TOC) is defined as Life Cycle Cost (LCC). "LCC (per DoD 5000.4M) includes not only acquisition program direct costs, but also the indirect costs attributable to the acquisition program (i.e., costs that would not incur if the program did not exist). (Gansler, 1998)" (Boudreau & Naegle, 2005). This concept is closer than previously held costs, and approaches the engineering management definition of a ship's life cycle.

Current Navy SR&M. Exhibit 1(adapted from Parnell, 2008, p. 56) indicates the NAVSEA Vessel Decision Process applied to vessel system whole life cycle, from inception to removal from service and disposal. This research is focused on the operational service life of the vessel.

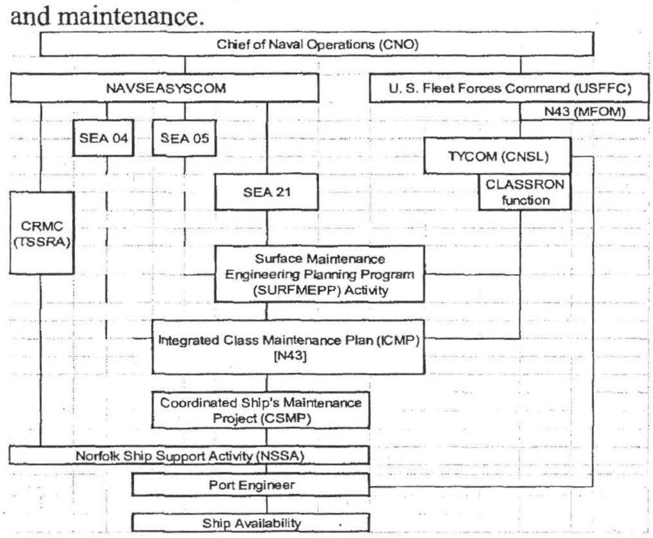
The Navy has determined that the ship's service life of 35 years to support current and future anticipated funding. This service life excludes the design and shipbuilding, and the transition to fleet reserve status, decommissioning, or foreign sales. Commander Naval Surface Forces Atlantic (COMNAVSURFLANT) launched in fall 2002, SHIPMAIN, which is, "improve maintenance planning for surface ships and nonnuclear aircraft carriers, from the point at which work is first identified by ship's force through the start of execution of that work in maintenance availability. It concentrates on gaining efficiencies across multiple organizations by identifying and eliminating redundancies" (Yardley, Raman, Riposo, & Chiesa, 2006). SHIPMAIN, an anachronism for Ship Maintenance, was to "improve the timeliness and quality of ship work candidates, as measured by the newly instituted metrics of Ship to Shore Cycle Time and Ship Work Candidate First Pass Yield" (Sydow, 2008). The cost of construction of these next-generation ships, budgetary restraints, and other factors have also made it necessary to maintain, adapt, and extend the life of the legacy fleet to meet operational requirements and maintain our maritime dominance (Dean, Reina, & Bao, 2008).

NAVSEA has conducted several interdisciplinary studies to address the high cost and extended duration of new vessel design and construction cost overruns. Naval architecture and force studies have been key components of these efforts. "Two general approaches are available: development of alternative future fleet design and programming concepts, and changes in expected service life policy. These are not mutually exclusive alternatives; service life is a key variable in future force planning regardless of any other variables considered" (Koenig, Nalchajian, & Hootman, 2008). "The Navy has not conducted a comprehensive study of a ship design to determine the relationship between cost-to-design-and-build and years of intended service life" (Koenig, et al., 2008).

Furthermore, the average age of the fleet will increase, so maintenance, repair, and modernization budgets will eventually rise. The Navy has a requirement to maintain 313-ship fleet over the next thirty years, and per-ship costs are rising (Koenig, et al., 2008). Currently, the anticipated force structure of the "current 30-year shipbuilding plan based on a 35-year average expected service life, which was asserted to be too long unless huge investments were made to keep old ships operational well beyond their intended and historical service life" (Koenig, et al., 2008). "The Navy will add five years to the planned 35-year service lives of its workhorse Arleigh Burke-class destroyers, according to the latest version of the service's 30-year shipbuilding plan ..." (Koenig, et al., 2008).

Navy leaders embarked on an "Enterprise" approach to operational readiness to deal with changing challenges of the 21st century. One CNO initiative is "Operations-Focused Maintenance" program. According to the Chief of Naval Operations, the Fleet Response Plan (FRP) is the operational framework intended to "...ensure continuous availability of trained, ready Navy forces capable of a surge response forward on short notice" (*OPNAVINST 3000.15 Fleet Response Plan (FRP)*, 2006). "The FRP is the construct within which the SWE (Surface Warfare Enterprise) must function. Implicit in the concept of the FRP is the need for high operational availability (AO) of naval forces. High AO directly affects the frequency and duration of maintenance opportunities" (Sydow, 2008). Project Risk Management from a life cycle application may minimize vessel total ownership cost to include design and construction, repair, and maintenance, optimize the scheduled for maintenance periods, and increase operational availability and surge readiness. Exhibit 2 provides a current view of the Navy's SR&M framework based on collected documentation and interviews.

Exhibit 2. Current procedure for US Navy ship repair and maintenance.



The Navy is using a Reliability Centered Maintenance and Condition Based Maintenance policy for ships, ship systems, and equipment (NAVSEA Instruction 4790.27 dated 16 Sept 2009).

Methodology

Construction of the framework from the theoretical concepts was constrained by the framework features previously discussed. The governing features were compiled from boundary conditions, the functional characteristics and framework influences and the pragmatic factors established for the framework, per framework influences shown in Exhibit 3.

Exhibit 3. Methodology for framework development.

System-Based Methods and Models	System Perspectives	System Principles	SR&M Project Risk Functions	SR&M Project Characteristics
Development Process	Systems Management	Context	Life Cycle Perspective	Systems Methodology
Improvement Process	Program Management	Hierarchy	Risk Assessment	Systems Based Models
Risk Assessment	Project Management	Satisficing	Complex System	PM Methodology
Life Cycle Process	Risk Management	Suboptimization	Decision Making	Risk Methodology
	Knowledge		PM Perspective	Life Cycle Methodology
	Cost Management			
	Life Cycle Management			
Systems-based Methods	Systems Perspectives	Systems Principles	SR&M Project Characteristics	SR&M Development Functions
Framework Elements		Framework Foundation	Framework Elements	
		Framework		

The governing features were compiled from boundary conditions and the functional characteristics relating to the theoretical concepts underlying the framework. The theoretical concepts were selected to reflect the pragmatic factors in establishing the underlying features of the proposed framework.

Construction of the framework from the theoretical concepts was constrained by the framework features. The governing features were a compilation of the boundaries and the utilitarian characteristics and factors established for the framework:

(1) Generalizable/Transportable to/for any complex system project.
(2) Analysis is based on systems principles.
(3) The framework validates its substantive meaning by comparison with empirical evidence and/or expert opinion.
(4) The framework must be easily understood by engineering professionals.

The shape and elements of the framework were a result of the application of the underlying theoretical concepts within the four governance factors.

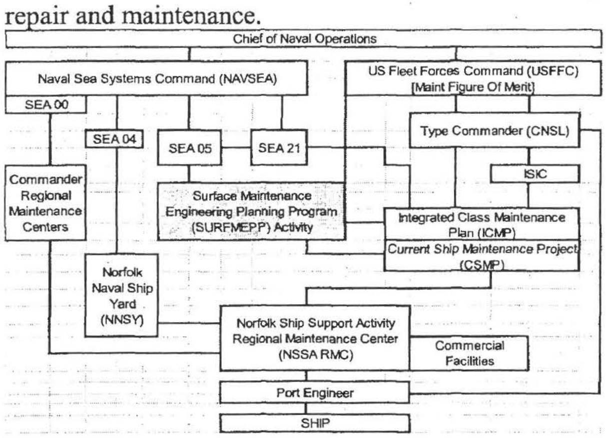
The organizations involved in the ship repair and maintenance process provide inspection, repair, and maintenance line items for each ship class, maintained in the Integrated Class Maintenance Plan (ICMP). The purpose is to ensure that the ship class ICMP and the ship's Current Ship Maintenance Project (CSMP) contains all inspections, repair and maintenance work items/jobs with note of their periodicity of scheduling. The purpose of the Surface Maintenance Engineering Planning Program (SURFMEPP) Activity is to identify items and making the case for their inclusion in each ship's availability work package conference. Their goal is to:

- o Ensure that inspections and SR&M work items be done on or before required periodicity.
- o Eliminate or drastically reduce the deferment of inspections and SR&M work items explicitly based on system, sub-system, or component life cycle assessment.
- o Planning and Engineering for Repairs and Ship-Alterations.

The Surface Maintenance Engineering Planning Program (SURFMEPP) Activity currently does not have any oversight authority to negate the deferring of inspections, repair and/or maintenance work items. Their role is limited to advising the TYCOM, while notifying NAVSEA 05 (technical authority) of the decision. U.S. Fleet Forces Command (USFFC) will accept the recommended decision unless extreme operational requirements dictate otherwise.

The Navy has many commands with many engaged and disengaged objectives in determining a ship's repair and maintenance scheduled availabilities. The framework delineates the changes to the current ship repair and maintenance process structure as well as the command actions and responsibilities. The proposed change will affect the decision making responsibility for deferring a ship's work package. The Surface Maintenance Engineering Planning Program (SURFMEPP) Activity will have oversight authority to restrict the deferring of inspections, repair and/or maintenance work items. U.S. Fleet Forces Command (USFFC) will accept the recommended decision unless extreme operational requirements dictate otherwise. Exhibit 4 indicates the lines of communication and authority.

Exhibit 4. Proposed framework for US Navy ship repair and maintenance.



Based on Exhibit 4, SURFMEPP will use project-risk based ship life cycle criteria, performing the decision analysis to determine what SR&M items are to be accomplished during a scheduled availability. The proposed framework for SR&M process diagram keeps the same lines of communication except the decision of deferring ship inspections, repairs and maintenance items will be made by the SURFMEPP Activity, with respect to the Type Commander (TYCOM) who retains the ultimate authority and final word based on fleet operational commitments. The following questions will be individually addressed:

1. Who will mandate the inspection schedule?
The inspection schedule will be mandated by USFFC and used by the SURFMEPP Activity. A risk management assessment should reinforce the periodicity for inspections, repairs, and maintenance that impact the ship's 35-year service life from the perspective of the ship operating at full capability.

2. Who will have oversight in determining if and when inspections, repairs, and maintenance work items will be scheduled for the current or next availability?
The inspection schedule, mandated by USFFC, will be controlled by the Surface Maintenance Engineering Planning Program (SURFMEPP) Activity from the depot repair and maintenance level. The focus should be the risks inherent to a single, cascading, or complete ship sub-system or system failure affecting the ship's readiness posture.

3. What information is needed to determine if the ship's service life is jeopardized and by whom?
The risk evaluation will include the future impact on the ship's life cycle cost, and the hull, mechanical, and electrical (HM&E) material perspective of the uncertainty in the ship maintaining a maximum readiness posture for a specific sub-system or system and its impact on other ship systems.

4. Are the stakeholders aware of the system risks of deferring inspections, repairs, and maintenance items or jobs?
The stakeholders may have other disengaged objectives outside the purview of each ship's repair and maintenance availability.

5. How may commands weigh the tradeoff between ship schedule and service life?
The decision to schedule and perform or not to perform any inspection, repair, and/or maintenance action should be made at the lowest level possible, and the framework indicates that the Surface Maintenance Engineering Planning Program (SURFMEPP) Activity is fully cognizant and capable of making the decision.

6. How can project risk management provide insight into the risks involved in ship repair and maintenance and provide an optimal balance of ship readiness over its 35 year service life.
The Surface Maintenance Engineering Planning Program (SURFMEPP) Activity, with input from all commands in the navy hierarchy via the ICMP, and the ship's CSMP as to what inspections, repair and maintenance projects and jobs will be scheduled for accomplishment at an upcoming scheduled availability period.

7. What alternatives/decisions need to be evaluated/made by whom and when?
The Integrated Class Maintenance Plan (ICMP) lists all the projects and jobs for each class of ships, and they are included in each ship's Consolidated Ships Maintenance Plan (CSMP). The projects and jobs are discussed at a Ship Availability Meeting, consisting of, but not limited to, the following organizational (stakeholders) representative(s):

- Ship: Commanding Officer, Chief Engineer, and Overhaul Coordinator
- Type Commander Representative (and Port Engineer)
- NSSA RMC: Project Manager and Waterfront Coordinator
- Surface Maintenance Engineering Planning Program (SURFMEPP) Activity {the proposed decision maker}
- Technical representatives (as needed)
- Facility Managers (government & commercial)
- Contractor(s) Project Managers and Specialists
- Other interested parties (as necessary)

The details of the upcoming availability are discussed concerning what can be accomplished during the timeframe allotted. Projects and job alternatives are discussed, evaluated, and decisions made based on facts and risks, materials and parts availability, equipment logistics, staging pier side, and available shore equipment, dry dock facilities and crane services, and supporting equipment and material handling vehicles.

8. What are the measurable outcomes if this framework is implemented?
The outcomes may not be realized for several years into the ship's service life as there will be an expenditure spike to enable the ship to catch up on deferred inspections and repairs or maintenance previously not accomplished, requiring worsened material conditions to be remedied at higher costs than if done years earlier. Secondly, the added or catch up work may impinge on current work items being accomplished within the scheduled availability period. This may require longer scheduled availabilities than previously scheduled. One potential outcome may be a reduction of total ship life cost. The ship cost outcome may not be realized for several years after the framework is used in a single ship pilot study, as there will be increased expenditures in the beginning to "catch up" with deferred inspections, repairs, and maintenance projects and jobs. The vessel life cycle cost should prove to be a good estimate of future repair and maintenance costs, based on future technological developments and

advances, and mission changes requiring added ship capabilities.

Exhibit 5. Result of framework validation.

Question	Survey Question	Responses		
		Positive	Neutral	Negative
1	What will be the short term impact on the ship availability process?	25%	56%	19%
2	What will be the long term impact on the ship availability process?	36%	61%	3%
3	What will be the scheduling impact on facilities/workforce for availabilities?	43%	48%	9%
4	What will be the scheduling impact on ship deployments?	50%	50%	0%
5	What will be the scheduling impact on the Total Ship System Readiness Assessment program?	31%	66%	3%
6	How will the new framework affect the Reliability-Centered Maintenance program?	30%	70%	0%
7	Will the proposed framework benefit a ship reaching its 35-year service life?	29%	71%	0%
8	Will the proposed framework contribute to better decision making in determining which repairs, maintenance, and inspections are to be accomplished during a scheduled availability?	50%	50%	0%
9	What concerns do you foresee in the Navy implementing the proposed framework?	9%	73%	18%

Analysis of Decision Making Process. Respondents directly or implicitly indicated that the complexity of the current ship repair and maintenance (SR&M) process being altered to a project-risk and life cycle based decision making ship repair process posed management of resources challenges. The positives are the ability to conduct ship life cycle inspections as a priority and a repeatable process. This will make ship service life more possible and the challenges would be management command and commercial resources and their allocation of available trained personnel, equipment, and facilities. The initial expenditure of resources would be considerable due to the catching up of inspection and repair and maintenance of items requiring a surge of commercial personnel and facilities.

The first page shall contain the title in full capital letters, centered across the entire page. Use 14-pt bold font for the title and leave a single blank line between the last line of the title and the first author's name. One line should be used for each author and should include the author's name, suffixes, and affiliation. Use 10-pt bold font for the author line(s). There should be a single blank line between the last author name and the next line containing a single drawn thin line. *Author names and biographical information will be omitted from the electronic copy before sending for blind review.* Another single blank line separates the drawn line and the text body as shown above.

The paper should include at least the following sections: abstract, introduction, text body, conclusions, and references. Acknowledgement of funding support and/or any other kind of assistance should be contained in an Acknowledgements section located immediately before the References.

Work Schedule and a "No Deferral" Imperative. Respondents cited the impact on the planning of deferred life cycle inspections, maintenance and repair work items that will be needed in the short term, causing a strain of facilities and manpower. After this initial backlog of inspections and work has been brought into line with life cycle parameters, there should be improved and better managed workloads during ship availability timelines, which would necessarily reduce job conflicts of overlapping work and the scheduling of dry dock facilities. Dependency relationships were based on an initial increase for the first few years of implementation. The coordination of governmental and commercial facilities and synchronization of ship funding relations for competing command interest and priorities may impede progress.

Focused Management Decision Needed. The ship repair system and organizations will need to better manage/coordinate initial increases in ship inspections, repairs and maintenance work. Surface Maintenance Engineering Planning Program (SURFMEPP) Activity was established to ensure a ship's 35-year service life. The organizational challenge will be to schedule deferred work in addition to other required or mandated work items. The focus will be to have every ship attain their full service life.

Exhibit 6. Survey response analysis by question. Results tabulated from Subject Matter Expert questionnaires and interviews are tabulated in Exhibit 6.

	Survey Questions	Responses		
		Positive	Neutral	Negative
Q1	What will be the short term impact on the ship availability process?	25%	56%	19%
Q2	What will be the long term impact on the ship availability process?	36%	61%	3%
Q3	What will be the scheduling impact on facilities/workforce for availabilities?	43%	48%	9%
Q4	What will be the scheduling impact on ship deployments?	50%	50%	0%
Q5	What will be the scheduling impact on the Total Ship System Readiness Assessment program?	31%	66%	3%
Q6	How will the new framework affect the Reliability-Centered Maintenance program?	30%	70%	0%
Q7	Will the proposed framework benefit a ship reaching its 35-year service life?	29%	71%	0%
Q8	Will the proposed framework contribute to better decision making in determining which repairs, maintenance, and inspections are to be accomplished during a scheduled availability?	50%	50%	0%
Q9	What concerns do you foresee in the Navy implementing the proposed framework?	9%	73%	18%

The framework was validated by Subject Matter Experts (SME) who are senior program (uniformed and civilian) managers working in the Navy's ship inspection, repair, and maintenance program from different commands. The results of these SMEs are documented in Appendix C of this author's dissertation. Their replies to the Questionnaire are noted with the analysis and synthesis of their validation comments on the proposed framework process. The key findings from the industry assessment are discussed and summarized in Exhibit 6. A question by question analysis of the subject matter expert's comments are tabulated and summarized by question:

- Question 1: The Subject Matter Experts indicated an overall positive expectation of 25% that the short term impact would be acceptable, and have a 19% negative impact on resource allocation.
- Question 2: The Subject Matter Experts indicated an overall positive expectation of 36% with only a 3% negative impact on long term resource allocation.
- Question 3: The Subject Matter Experts indicated an overall positive expectation of 43% with only a 9% negative impact on the scheduling of resources.
- Question 4: The Subject Matter Experts indicated an overall positive expectation of 50% with a zero negative impact on the scheduling of ship deployments.
- Question 5: The Subject Matter Experts indicated an overall positive expectation of 31% with a 3% negative impact on the scheduling of the Total Ship System Readiness Assessment program.
- Question 6: The Subject Matter Experts indicated an overall positive expectation of 30% with a zero percent negative impact on the Reliability Centered Maintenance program.
- Question 7: The Subject Matter Experts indicated an overall positive expectation of 29% with a zero percentage negative impact on a ship reaching its 35-year service life.
- Question 8: The Subject Matter Experts indicated an overall positive expectation of 50% with a zero percent negative impact that the decision making f process for a ship's availability work package would improve.
- Question 9: The Subject Matter Experts indicated an overall positive expectation of 9% with an 18% negative impact for concerns that the framework would be implemented.
- The aggregate analysis of the Subject Matter Experts indicated an overall positive expectation of 34% with a 6% negative impact on the proposed framework and its benefit in improving the Navy's ship repair and maintenance program.

Summary

The results of the research study contribute to existing and future research in several ways. First, the study provides evidence that a systems-based project risk management and life cycle assessment framework for the ship repair and maintenance selection process can improve ship readiness and reduce ship life time costs. The study provides the evidence that a systems-based framework for the Navy's SR&M program may be reliably applied to other complex systems. This is important in that the framework is generalizable due to the fact that the theory represents a large variety of facts.

The development of a framework requires the same requires the same rigor as the development of a theory, and must be based on scientific inquiry. Failure to base the development of a framework on rigorous research may limit the utility of the framework by failing to include relevant data or exclude irrelevant data. The use of a formal method for the development of a framework, based on systemic principles, ensures that the framework addresses all of the relevant data.

Secondly, the study provides a framework which may be used to conduct additional research on complex system projects. The ability to expand the research to projects with different characteristics is an immediate objective for generalization of other research efforts, extending its applicability and utility.

Finally, the research makes a significant contribution to the body of knowledge on qualitative research in engineering management of complex systems.

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