Level of Repair Analysis for the Enhancement of Maintenance Resources in Vessel Life Cycle Sustainment

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Dedication

This praxis is dedicated to my wife, Tammie, and our beautiful children Caleb, Gabriel, and Madelyn. You allowed me to embark on this personal endeavor by willingly sacrificing our valuable time together. Your love sustained me through these most challenging times. Tammie, I was continuously inspired by your unrelenting support. You willingly accepted the burden of my absence when you could have easily done otherwise.

This praxis is also dedicated to my parents, Charles and Barbara Marino, who instilled in me the value of hard work, education, and dogged perseverance. Dad, throughout my life I watched you work harder than reasonably expected to produce the best life possible for your family. I always gauge my own work against the standard which you set and to this day, I am rarely capable of approaching the baseline. You are the hardest working person alive. Mom, I watched you put yourself through college as a young mother with two children and a deployed husband. You were the first person in our family to attend college. Through your example, you showed me the importance of education. I honor your achievement by continuing the tradition that you started. In this way, my achievement is a continuation of yours.

Lastly, this praxis is dedicated to the hard-working naval engineers of the U.S. Coast Guard. You keep the lights burning and the screws turning against all odds. Your hard work keeps the world’s greatest maritime service afloat and I’m proud to call you my brothers and sisters.
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Abstract of Praxis

Level of Repair Analysis for the Enhancement of Maintenance Resources in Vessel Life Cycle Sustainment

The United States Coast Guard does not adequately perform a Level of Repair Analysis and Business Case Analysis to align vessel maintenance requirements with available resources during the development of an Integrated Logistics Life Cycle Plan (ILSP) which leads to increased vessel sustainment costs and reduced workforce proficiency. The ILSP’s maintenance philosophy dictates the designed supportability and maintainability of a vessel throughout its life cycle yet existing ILSPs fail to prescribe the required balance of Coast Guard (internal employees) and non-Coast Guard (contracted) technicians for the execution of hull, mechanical, and electrical depot maintenance. This research develops a standard model to enhance the balance of maintenance resources using a Business Case Analysis (BCA) extension of a Level of Repair Analysis (LORA) informed by Activity-Based Costing Management (ABC/M) theory. These analyses are integral to a complete Life Cycle Cost Analysis (LCCA) and will contain a simplified LORA framework that provides an analysis of alternatives, a decision analysis, and a sensitivity analysis for the development of a maintenance philosophy. This repeatable analysis can be used by engineering managers to develop and sustain cost-effective maintenance plans through all phases of a vessel’s life cycle (acquisition, sustainment, and disposal).

Keywords: Engineering logistics, maintenance analysis, level of repair analysis
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<thead>
<tr>
<th>Acronym</th>
<th>Meaning</th>
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<tbody>
<tr>
<td>ABC/M</td>
<td>Activity-Based Cost Management</td>
</tr>
<tr>
<td>BCA</td>
<td>Business Case Analysis</td>
</tr>
<tr>
<td>CG-LIMS</td>
<td>Coast Guard Logistics Information Management Systems</td>
</tr>
<tr>
<td>DAU</td>
<td>Defense Acquisition University</td>
</tr>
<tr>
<td>DOD</td>
<td>Department of Defense</td>
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<tr>
<td>FRC</td>
<td>Fast Response Cutter</td>
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<tr>
<td>GAO</td>
<td>Government Accountability Office</td>
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<tr>
<td>ICGS</td>
<td>Integrated Coast Guard Systems, LLC</td>
</tr>
<tr>
<td>ILSMT</td>
<td>Integrated Life-cycle Support Management Team</td>
</tr>
<tr>
<td>ILSP</td>
<td>Integrated Life-cycle Support Plan</td>
</tr>
<tr>
<td>LORA</td>
<td>Level of Repair Analysis</td>
</tr>
<tr>
<td>LREPL</td>
<td>Long Range Enforcer Product Line</td>
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<tr>
<td>LTA</td>
<td>Logic Tree Analysis</td>
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<tr>
<td>MAT</td>
<td>Maintenance Augmentation Team</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>--------------</td>
<td>------------------------------------</td>
</tr>
<tr>
<td>MEC</td>
<td>Medium Endurance Cutter</td>
</tr>
<tr>
<td>MTBF</td>
<td>Mean Time Between Failures</td>
</tr>
<tr>
<td>MTBM</td>
<td>Mean Time Between Maintenance</td>
</tr>
<tr>
<td>NED</td>
<td>Naval Engineering Department</td>
</tr>
<tr>
<td>NSC</td>
<td>National Security Cutter</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
</tr>
<tr>
<td>RCM</td>
<td>Reliability Centered Maintenance</td>
</tr>
<tr>
<td>SFLC</td>
<td>Surface Forces Logistics Center</td>
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<tr>
<td>USCG</td>
<td>United States Coast Guard</td>
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Chapter 1. Introduction

As Coast Guard ships (referred to as cutters) are commissioned, the Coast Guard relies heavily on contracted technical support for the completion of preventative maintenance and the resolution of equipment casualties (corrective maintenance). As a cutter matures, the desire to transition from contracted support to internal Coast Guard technicians increases (USCG, 2013). Building a realistic maintenance plan to support this transition requires the analysis of maintenance requirements and resources and the development of internal Coast Guard workforce proficiency through formal training, experience, and a strategic maintenance philosophy (Flannery, 2017). Ultimately, a balance of both Coast Guard and commercial maintenance resources must be established to support this strategy.

1.1 Problem Description

During the recent acquisition of two cutter classes, the Coast Guard strategically diverted the assignment of preventative and corrective maintenance tasks from internal Coast Guard technicians to contracted (non-Coast Guard) technicians to reduce training and manning costs which resulted in reduced internal workforce proficiency and increased life cycle maintenance costs (DiPietro, 2017). Reduced service funding, demanding operating schedules, the adoption of increasingly advanced technologies, insufficient acquisitions logistics plans, and a low-risk tolerance caused sustainment-focused engineering logistics centers to default first to contractors for maintenance (DiPietro, 2017). This strategy delayed the service’s development of training courses and capabilities for Coast Guard technicians (internal military and civilian trade employees),
increased cutter maintenance costs, and introduced schedule constraints associated with the limited availability of non-Coast Guard technicians. As a result, the most modern and technologically advanced ships in the fleet lack resident technical training courses, receive little Maintenance Augmentation Team (MAT) support, and are minimally manned to reduce operating costs (USCG, 2013). These factors further exasperate a dependency on contracted support in an environment of slowly dwindling resources.

The Government Accountability Office (GAO) documented Coast Guard maintenance cost issues in their report titled, *Coast Guard Cutters: Depot Maintenance Is Affecting Operational Availability and Cost Estimates Should Reflect Actual Expenditures*. GAO states “…maintenance work for the FRC (Fast Response Cutter) and WMSL (National Security Cutter) fleets has lowered the operational availability of each fleet.” “To ensure that it efficiently uses its resources, the Coast Guard should document cost analysis on the cost and timing of engineering design changes and periodically evaluate and update its depot maintenance cost estimates” (GAO, 2017). These statements support this praxis’s proposal to perform iterative LORAs with a focus on Activity-Based Cost Management.

1.2 Solution Approach and Significance (*Thesis and Elaboration*)

An appropriate balance of Coast Guard technicians and commercial resources is required to reduce vessel maintenance life cycle costs and improve Coast Guard workforce proficiency (thesis statement). The Coast Guard and Department of Defense prescribe rigorous maintainability and sustainability analyses throughout a vessel’s life cycle to determine the type, quantity, and employment of the aforementioned resources. In particular, Level of Repair Analysis (LORA) is an analytical methodology used to
determine whether an item will be replaced, repaired, or discarded based on cost considerations, unit maintenance capabilities, and operational readiness requirements (USCG, 2014). LORA considers noneconomic factors to inform initial support decisions and economic factors to determine the most cost-effective method to sustain a system throughout the life cycle (USCG, 2014). Although military and industry publications prescribe LORA methods, they fall short of providing detailed guidance for the performance of LORA. The Coast Guard’s Reliability Program defines a strategic framework for LORA but does not describe in detail economic, decision, or sensitivity analysis methods. This research will provide a rigorous, relevant, and repeatable method for executing LORA on Coast Guard assets which may be adopted by engineering managers in industries concerned with maintenance programming.

Historical maintenance performance data contained in Chapter 4’s case study on Medium Endurance Cutter (MEC) propulsion engine maintenance indicates that Coast Guard technicians may be the most cost-effective maintenance resource, one which provides mission-essential flexibility in a blended resource plan. The maintenance philosophy established to maintain legacy Coast Guard vessels (those commissioned before 1990), such as the MECs, prioritizes the use of Coast Guard technicians. Under the legacy philosophy, Coast Guard technicians develop expertise through equipment-specific training and the routine execution of maintenance tasks. Further, the use of Coast Guard technicians reduces schedule and cost barriers inherent in contracting processes and provides a cost-effective and highly responsive maintenance program. However, Coast Guard depot maintenance technicians exist in limited numbers, take years to develop, are subject to military reassignment every four years, and lack proficiency and
in the most advanced maintenance tasks. Therefore, the Coast Guard will never be fully self-reliant and will require a measure of contracted technicians from industry (original equipment manufacturers or equally qualified technicians) to provide the most advanced depot maintenance support. Conducting a suitable LORA, initially during cutter acquisition and iteratively during sustainment, will identify the balance of Coast Guard technicians and commercial resources required to reduce vessel maintenance life cycle costs and improve Coast Guard technician proficiency.

1.3 Organization of Chapters

This praxis is organized into Chapters. Chapter 2, Literature Review, provides a thorough review of Coast Guard policy and directives, Department of Defense guidance, and academic literature to support the proposed LORA methodology and performance of the case studies. Chapter 3, Research and Methodology, presents a framework for the proposed methodology and research contained in this praxis to include assumptions, objectives, variables (dependent and independent), and a detailed description of the proposed Level of Repair and Business Case Analyses (LORA/BCA) framework. Chapter 4, Results, provides a case study of the NSC (National Security Cutter) representative of an analysis conducted during the acquisitions phase of a cutter’s life cycle followed by two validation events. Validation is first accomplished through a LORA/BCA of the Legend Class Medium Endurance Cutter (MEC) using historical depot maintenance data recorded during the sustainment phase of a cutter’s life cycle. The second validation effort provides a peer review of the NSC and MEC case studies by a team of subject matter experts from cutter acquisition, sustainment, and training commands. Chapter 5, Discussion and Conclusion, discusses the ability of the proposed
framework to meet the research objective, answer the research questions, and reject or accept the hypothesis.
Chapter 2. Literature Review

Level of Repair Analysis is believed to have first emerged within the Department of Defense (DOD) as Item Repair Level Analysis (IRLA) in the 1970s (Briskin & Demmy, 1988). LORA matured over the course of a decade to become “a prescribed procedure for defense logistics support planning. For a complex engineering system containing perhaps thousands of assemblies, sub-assemblies, components, etc., organized into several levels of indenture and with a number of possible repair decisions, LORA seeks to determine an optimal provision of repair and maintenance facilities to minimize overall life-cycle costs” (Gutin, et al., 2006). Douglas (1990) describes indenture as "a relationship between parts and their components. A two-indenture system involves a part with components. A three-indenture system involves a part with components that have subcomponents." Basten, et al. (2008), agree and propose that military naval equipment with multiple levels of indenture require a robust multi-echelon repair network that connects vessels with shoreside maintenance resources. This is part of the determination for "where" maintenance is completed. Douglas (1990) describes echelons as “a term which describes a relationship between two or more successive repair level decision points. A two-echelon system usually involves a base and depot, the depot being the site of more extensive diagnostic/repair capability." Bi-level and tri-level maintenance networks fit the aforementioned two- and three-echelon systems.

According to Cruyt, Ghobbar, and Curran (2014), “supportability is often called logistic support, and is traditionally referred to as integrated logistic support (ILS). Supportability is included when dealing with reliability, availability, maintainability, and
supportability (RAMS)”. Reliability engineers dedicate significant effort to maximizing system availability while considering the dependencies of reliability and supportability (Wing & Crow 1990). Zwissler and Toole (1990) describe the importance of performing integrated logistics analyses, notably those related to supportability, in the cost-effective design of complex systems. They note that “although, intuitive to many in concept, application of developmental supportability engineering and logistics analytical conventions to influence system design during development is inherently difficult.” It is very difficult to predict support requirements based on early design requirements due to a lack of performance data and design immaturity (Zwissler & Toole, 1990). As system design matures, the ability to change logistics decisions becomes more costly to the organization. Performance data quality can be improved through standardized collection and analysis methods. Wang and Xiang (2014) state that “it should be noted that when sufficient data is not available, engineering judgment is needed to subjectively estimate the repair effectiveness values. This may add some level of uncertainty into the prediction”. This praxis proposes an iterative LORA begin as early in the design process as possible to minimize supportability risks and reduce uncertainty. This praxis also presents a standardized methodology that can be uniformly applied to both early design (acquisition phase) and mature system (sustainment phase) support.

In addition to identifying “where” maintenance is completed, LORA determines the scope of maintenance to be performed at the organic, intermediate, and depot levels and their required resources (Briskin & Demmy, 1988). Depot resources can be either internally (parent organization) or externally (industry contractor) sourced. Basten (2008) identified a "trend that customers outsource activities for system upkeep to the original
equipment manufacturer (OEM) using service contracts that guarantee a certain service level against fixed yearly costs. The Coast Guard’s decision to assign preventive and corrective maintenance tasks to OEM contractors contributes to this trend (Section 1.1).

Manna (2007) notes how LORA translates "the design characteristics into recommendations for those resource requirements that will be needed to support system maintenance e.g. number of maintenance personnel need, training requirements, spares and spare locations, facilities, etc. When maintenance drivers are identified, feedback loops allow Systems Engineering to assess requirements and those design attributes that are driving the maintenance costs. This enhances the trade space for systems engineering to make changes to the system requirements, reducing maintenance and lowering the overall cost of ownership."

The majority of the academic publications reviewed in the course of this praxis do not address the phases of LORA. However, Liu, et al. (2010), specifically discuss non-economical LORA (referred to as NELORA) and economic LORA (referred to as ELORA) in their paper, “The Application of Multi-agent Technology on the Level of Repair Analysis”. Liu, et al. (2010), acknowledge six cost drivers for ELORA to include inventory, support equipment, space, labor, training cost, and documentation. “Basically, this approach involves pricing all of the logistics costs associated with each RLA option, and selecting the least cost alternative on an item by item basis” (Briskin & Demmy, 1988). Unfortunately, Liu et al. hesitate to provide a detailed LORA process or mention any decision or sensitivity analysis methods.

Barros (2001) noted the importance of considering fixed and variable costs during LORA. Barros, like most researchers, applied LORA solely to corrective maintenance
actions and investigated various methods to determine the appropriate level of repair in multi-echelon networks. Barros (2001) stated that “the upward tendency of maintenance costs will probably lead the Western world to adopt planned maintenance techniques similar to Total Productive Maintenance (TPM) programmes adopted by the Japanese manufacturing industry which is applicable to many industries”. This praxis proposes the use of variable preventive (planned) maintenance task data (e.g. labor hours) to calculate costs and complete sensitivity analysis.

To address decision analysis, DOD has championed several computer-based LORA decision support systems (DSS) since the 1980s. Girz (1989) described the value of DSS for “quickly assisting managers in making effective decisions in those areas where both management judgment and computer analysis are required”. Computer-based programs help organize and compute the overwhelming quantity of data required to complete LORA on robust platforms. The availability of computer-based programs improves the probability that a rigorous analysis will occur if provided to the appropriate users. Componation, Dorneich, and Nicholls (2017) studied the behavior of decision analysts in the selection and use of multiple decision analysis methods. They determined that less technically-challenging decision analysis approaches provided analysts with higher confidence in decision analysis tools and the ability to communicate functions and results to their superiors (Componation, et al., 2017). These findings support the use of simplified methods and tools for LORA found in DSS and the method proposed by this praxis.

LORA also has significant implications for supply chain management. Werme, Eriksson, and Righard (2017) called for a change to traditional LORA due to its inability
to consider the costly impact that repair level decisions have on spare parts investment. Werme, et al, propose “a new approach to LORA which takes the simultaneous optimization of stock, resources and maintenance capability into account. It is demonstrated that not treating these decision variables as dependent will render suboptimal support system designs and it is stressed that the interconnection between them should be taken into account when making decisions regarding the support system.” Xue, Xiao, Li, and Ma (2016) agree with the call for improved alignment of repair/discard and spare part decisions. Triki, Alalawin, and Ghiani (2013) define the value of LORA to supply chain management as “defining the optimum tradeoff between the availability of both spare parts and maintenance resources. High spare parts inventories avoid intense employment of the maintenance resources, vice versa increasing the resources capacity will accelerate the repair process and avoids to have high inventories”. Manna (2007) agreed with the systemic relevance of LORA/Repair Level Analysis on supply decisions in "Quantitative Determination of Maintenance Concepts for COTS Based Systems". Manna (2007) focused primarily on Commercial-off-the-Shelf (COTS) items which are prevalent on military naval vessels. Enhanced systems integration complicates maintenance concepts and increases the need for “logistics tail” analysis (Manna, 2007). Manna (2007) recommends that LORA (or RLA) should be applied to entire systems, not single COTS items. Each item may have a unique life cycle, maintenance requirements, and resource demands that impact the system’s maintenance concept (Breidenbach, 1989). The new environment may be different than that for which the COTS item was designed. There may be design dependencies for the COTS item that are impacted by system elements. "COTS-based sub-system RLA
(Repair Level Analysis) modeling supports determination of the type of warranty, spares, repair contracting, and technical performance measures associated with Supply Chain Management” (Manna, 2007).

2.1 Coast Guard Policy and Directives

The Coast Guard prescribes LORA through policy but fails to provide detailed direction on how to execute the analysis. The Coast Guard establishes the requirement to conduct a LORA in the Surface Forces Logistics Center (SFLC) Reliability Program Process Guide. Appendix B of the Process Guide defines LORA as “An analytical methodology used to determine where an item will be replaced, repaired, or discarded based on cost considerations, unit maintenance capabilities, and operational readiness requirements.” It goes on to state, “During follow-on actions to determine if existing maintenance is applicable and effective, LORA may be reevaluated or renewed based on cost, capability or readiness requirement changes” (USCG, 2014).

The Process Guide provides two basic objectives of a LORA, the first of which is to analyze maintenance support alternatives based on economic and noneconomic factors relating to the system, and the second which is to use the results of the analysis to assist in maintenance planning process which will achieve the most effective maintenance support structure (USCG, 2014). These objectives justify the two case studies found in Chapter 4 of this praxis and the creation of the standardized LORA model proposed by this research. They also support the iterative completion of a LORA throughout Coast Guard vessel sustainment to inform the Integrated Logistics Support Plan (ILSP) and maintenance resource allocations. Unfortunately, these iterative sustainment phase LORAs are not occurring, thereby inhibiting strategic maintenance decisions. This
research proposes mandating a LORA at four-year intervals to align with logistics planning phases.

Before conducting a LORA, the Coast Guard completes a Logic Tree Analysis that determines whether preventative maintenance is justified for equipment. If the financial, safety, environmental, and operational costs of a corrective action is less than that of a preventative maintenance action, the LTA identifies the item as a run to fail and the LORA will determine the logistics of the corrective maintenance task. This praxis proposes that the application of LORA to corrective actions does not negate the utility of LORA to analyze the cost of preventative maintenance during the development of a maintenance philosophy. This research contends that the LORA executed in the acquisition phase relies primarily on preventative maintenance task data provided by original equipment manufacturers to estimate the costs of both preventative and corrective maintenance actions. Well-defined preventative maintenance tasks provide the planned frequency, duration, required supplies, and technician requirements (qualification level and quantity of technicians) needed to execute a task regardless of whether being performed as preventative or corrective maintenance. Preventative maintenance tasks and manufacturer technical publications (repair manuals) are often the only extant data sources available during analysis in acquisitions and early sustainment phases. Additionally, when corrective actions are performed by field technicians, the same procedure provided for many preventative maintenance tasks is followed to complete corrective maintenance on the same component with the only difference being the stimulus for action (planned vs. unplanned). The procedures and resources shared by preventative and corrective maintenance justify the application of LORA for both.
The Reliability Program Process Guide directs the completion of non-economic and economic analyses after the LTA. These analyses provide inputs to determine where maintenance should be conducted. According to the Process Guide, LORA determines if it is cost effective to conduct maintenance, whether the item should be repaired or replaced, and whether the item should be repaired or replaced at the operational (O) or depot (D) level in alignment with the Coast Guard’s bi-level maintenance model.

Regarding the discard, repair, or replace determination, the LORA process may discover that replacing an inexpensive part is unreasonable when considering all costs. The LORA determines if it is more cost effective to discard an item than attempt to repair it.

According to the Reliability Program Process Guide, a non-economic LORA is, “based upon a set of predefined questions or criteria. Non-economic LORA decision criteria are a list of rules or guidelines to determine if there is an overriding reason why maintenance should be performed. This logic can be modified to take into consideration other maintenance constraints, as dictated by a customer, or criteria such as operational environmental restrictions.” (USCG, 2014)

An economic LORA follows the non-economic LORA. The Reliability Program Process Guide states that “…candidates for an Economic LORA are selected and worked in conjunction with the maintenance concept” which “provides details about the level of maintenance and what type of maintenance activities are implemented at each level.” (USCG, 2014). According to the Process Guide, “The object of the Economic LORA is to determine the optimum repair strategy for an end item or equipment. An Economic LORA considers all associated support cost drivers (e.g., manpower, support equipment, training, transportation, etc.) required at each level of maintenance.” (USCG, 2014)
During acquisitions, analysts work with significant assumptions related to task level (O- or D-level maintenance), duration (expressed in hours), and impacts (Mean Down Time impacting availability, resource demands, supply chain impact). Analysts may assume that the Coast Guard traditionally completes preventative or corrective maintenance (and with certain resources) on similar components/units on other fielded systems of similar design. This is very important as it shows how the initial logistics resource decisions associated with an acquisition do not happen linearly as they may in sustainment. Development of the maintenance philosophy and economic analysis may occur in parallel versus series.

The Economic LORA will recommend a repair strategy based on economic rationale (USCG, 2014). SFLC references the models contained in MIL-HDBK-1390 for the analysis of cost drivers which include inventory cost, support equipment, space (for inventory), labor cost, training cost, and documentation (USCG, 2014). The economic analysis proposed in this praxis’s methodology (Chapter 3) includes these cost factors and notes the especially impactful costs of training and labor. SFLC recommends the use of a cost to repair screen which is “an equation used to determine if it is economically feasible to repair an item” (USCG, 2014). The formula for Cost to Repair Screen is:

\[(\text{Mean Time to Repair} \times \text{Labor Rate}) + \text{Equipment Cost}\]  \hspace{1cm} (2.1)

In the Cost to Repair Screen, equipment cost includes the cost of tools, parts, and supplies. The Process Guide dictates that a part should be recommended for a “replace and discard” decision if the procurement cost of the part is less than the Cost to Repair Screen cost. In other words, if it’s cheaper to buy an item than to repair it, the analysis defaults to “replace and discard”. If the procurement cost is greater than the cost to repair
an item, the analysis will result in a “repair” decision and a determination for the level of repair (O- or D-level).

This approach is logical for general equipment but is less effective for advanced systems with thoroughly researched and designed maintenance programs. In these cases, applying an Activity-Based Cost Management approach will shift the strategic focus from the part to the maintenance task which aligns with programmed depot maintenance plans, default MAT task assignments, and the development of strategic maintenance budgets. Focusing solely on components when developing O-level maintenance determinations has historically resulted in underestimating the resource loads at operational commands. Every Coast Guard cutter acquisition in the past twenty years has experienced this misalignment and resulted in deferred O-level maintenance and an unplanned performance of O-level maintenance by D-level resources. Unfortunately, the SFLC LORA guidance ends with the level of repair recommendation predicated on the lowest cost option without performing decision, risk, or sensitivity analyses. This praxis takes LORA further and better aligns with the recommendations of the Department of Defense (MIL-HDBK-1390 and Defense Acquisition University content) and Professor Benjamin Blanchard.

Liu, Tang, Zheng, Zhu, and Wang agree with the Coast Guard's use of a cost screen when deciding whether to repair or discard an item. They state that, "When determining if an item or sub-tem should be replaced and/or repaired at certain level of repair, consideration must be given to all aspects of the maintenance task. These include fault diagnostic techniques, accessibility requirements, task verification, elapsed task times, disruption to the operational environment etc (Liu, et al., 2010)." This aligns with this
praxis’s focus on task data to include procedure, complexity, duration, operational impact.

2.2 Department of Defense Level of Repair Analysis Guidance

The Department of Defense (DOD) presents a LORA framework in MIL-HDBK-1390, dated 29 January 2015 and through several Defense Acquisition University courses. These resources provide information and guidance on the completion of LORA without serving as a policy to mandate LORA. This provides DOD analysts with creative liberties at the cost of mandating a standard methodology.

MIL-HDBK-1390 is DOD’s most recent and relevant publication for the completion of LORA. As previously stated, MIL-HDKB-1390 is only guidance and not a policy document. MIL-HDBK-1390 references the life cycles defined by SAE AS1390, Level of Repair Analysis (LORA) and defines LORA as a “…analytical effort undertaken to influence decisions on a system’s design, maintenance planning, cost, and Integrated Product Support (IPS) Element resources” (DOD, 2015).

MIL-HDBK-1390 intentionally avoids providing granular guidance due to LORA’s application to a vast array of assets and situations. The handbook provides a sound framework that very closely aligns with the framework presented in the Coast Guard’s Reliability Program Process Guide. The alignment between Coast Guard and DOD guidance are beneficial as both services have similar requirements for the acquisition and sustainment of military vessels.

MIL-HDBK-1390 briefly describes the relationship between a well-executed LORA and maintenance planning, maintainability and reliability engineering, and provisioning. The focus on maintenance planning has the most relevance to this praxis. MIL-HDBK-
1390 defines maintenance planning as, “the process conducted to evolve and establish maintenance concepts and requirements for a materiel system” and notes that LORA, “identifies the recommended maintenance levels and support costs associated with unscheduled maintenance costs” (DOD, 2015). Although these statements are true, this praxis contends that in many cases LORA applies to scheduled maintenance tasks as well. This point will repeat in a review of all LORA literature found in this praxis. LORA can be applied to a review of prescribed maintenance programs when advanced, and well-supported, assets are procured from professional commercial vendors. The case studies in Chapter 4 show an application of LORA to maintenance tasks versus engine components. While it can be stated that an item has different support requirements depending upon whether it is replaced or repaired, it is also possible to capture the differences in resource requirements to do so, especially technician skill levels, tools, and supplies. In fact, one can assume that a task requiring replacement or repair on a planned basis is easier to analyze than an unscheduled task which comes with an increased margin of uncertainty related to equipment condition, failure timing, and resource availability at the time of failure. The literature review has not revealed arguments against this assumption.

MIL-HDBK-1390 makes excellent points regarding the long-term costs and risks imposed by deferring the near-term costs of completing a thorough LORA in acquisitions. The deferment of a detailed LORA negatively impacts the completion of related acquisition phase analyses (e.g., Materiel Solution Analysis, Technology Maturation and Risk Reduction, Failure Modes and Effects Analysis, and Manpower Requirements Analysis). The same is true of systems in the sustainment life cycle phase. MIL-HDBK-1390 states that “LORAs should be conducted on all fielded systems
upgraded, or in the process of being upgraded, to determine whether the materiel change or improvement will have an impact on the existing maintenance concept” (DOD, 2015). It also states that LORA can be completed whenever LORA report recommendations become invalid or maintenance concepts identified by a LORA and those observed in practice misalign. (DOD, 2015). This praxis agrees with those points and further advises that LORA should be iteratively conducted on fielded equipment of significant complexity and operational and financial value regardless of whether or not upgrades occur. Normally, equipment of this nature is supported by an evolving maintenance program that can benefit from updated LORAs. It should not be assumed that LORAs on unchanged systems will produce repeated results as support elements and maintenance demands may change with system maturity and require changes to maintenance program design. These changes may impact resource demands, equipment readiness, policies, and the maintenance philosophy. Changes internal and external to the organization may also contribute to the need for an iterative LORA. Changes to policies, laws, resource availability, and organizational processes influence LORA.

MIL-HDBK-1390 notes that LORA can be completed using various models or techniques. This praxis focuses on analyzing maintenance tasks, presents standard forms for the collection and analysis of information, and recommends routinely scheduled reviews of LORA as opposed to occasional sustainment completion. This praxis presents a methodology that may benefit many types of organizations, both public and private, and agrees that LORA should be catered to the organization it serves.

MIL-HDBK-1390 provides strong support for sensitivity and decision analyses. It outlines the relationship between sensitivity analysis and the management of program
risk. Notably, this relationship may be most critical and beneficial during the acquisition phase due to the uncertain condition of qualitative and quantitative data to the LORA.

The Defense Acquisition University (DAU) hosts two courses to advance military knowledge of LORA. Their introductory course, CLL 057 Level of Repair Analysis is based on the guidance of MIL-HDBK-1390 with an emphasis on the value, history, and elements of LORA. The curriculum discusses LORA’s relationship with related engineering logistics analyses (e.g., maintainability, reliability, and sustainability analyses). 057 also briefly explains measures of operational and materiel availability, ownership cost, and material reliability (DOD, 2014). In these ways, DAU contributes a strategic understanding of the value of LORA.

DAU course CLL 058 Level of Repair Analysis (LORA) - Theory & Principles provides an overview of the LORA methodology presented in MIL-HDBK-1390. CLL 058 describes the framework and activities recommended by DOD including noneconomic and economic analyses, levels of indenture, support contracting options, and repair level selection.

A notable disparity between DOD and Coast Guard LORAs is their dependency upon different levels of repair. DOD policy is founded on application to a tri-level maintenance model which provides for Organizational (O-level), Intermediate (I-level), and Depot (D-level) maintenance. The Coast Guard adopts a bi-level maintenance program which absorbs DOD’s I-level maintenance into its D-level maintenance. This difference is considered by some maintainers as a matter of semantics since both models provide full program design and resources exist at the same levels despite the difference in the assignment. For example, the Navy considers a ship as O-level, the government-owned
shore support facility as I-level, and the manufacturer’s facility as D-level while the
Coast Guard considers a ship as O-level and both government-owned shore support
facilities and manufacturer’s facilities as D-level. A more thorough description of the
Coast Guard’s bi-level maintenance model is provided in Chapters 3 and 4 of this praxis.

2.3 Benjamin Blanchard’s Level of Repair Analysis Guidance

There is a noticeable lack of LORA information originating from outside of the
operations research community. Basten, van der Heijden, and Schutten agreed with this
observation by stating, "Surprisingly, the scientific literature on LORA is limited (Basten,
et al., 2008)." Benjamin S. Blanchard provides the best non-proprietary text identified by
this research to outline a framework for the execution of a LORA. Blanchard describes a
framework for completing a LORA in sections of his textbooks, System Engineering and
Analysis, and Logistics Engineering and Management. Blanchard’s direction regarding
repair or discard decisions aligns with both Coast Guard and DOD guidance.

Blanchard summarizes the purpose of LORA by stating “In expanding the
maintenance concept to establish criteria for system design, it is necessary to determine
whether it is economically feasible to repair certain assemblies or to discard them when
failures occur. If the decision is to accomplish repair, it is appropriate to determine the
maintenance level at which the repair should be accomplished (e.g., intermediate
maintenance or supplier/depot maintenance” (Blanchard, 2014).

“Based on the results…the analyst knows that repair-level decisions highly depend on
the unit acquisition cost of each assembly and the total estimated number of replacements
over the expected life cycle (e.g., maintenance actions based on assembly reliability)”
(Blanchard, 2014).
“...the decision tends to shift from discard to repair at the intermediate level as the unit acquisition cost and the number of replacements increase (or the reliability decreases)” (Blanchard, 2014).

“In instances where the individual analysis result lies close to the crossover lines...the analyst may wish to review the input data, the assumptions, and accomplish a sensitivity analysis involving the high-cost contributors. The purpose is to assess the risk involved and verify the decision” (Blanchard, 2014).

“First, the decisions...may be accepted without change, supporting a mixed policy with some assemblies being repaired at each level of maintenance and other assemblies being discarded at failure. With this approach, the analyst should review the interaction effects that occur (e.g., the effects on spares, use of test and support equipment, maintenance personnel use, etc.). In essence, each assembly is evaluated individually based on certain assumptions, the results are reviewed in the context of the whole, and possible feedback effects are assessed to ensure that there is no significant impact on the decision” (Blanchard, 2014).

“A second approach is to select the overall least-cost policy for all 15 assemblies treated as an entity (e.g., assembly repair at the supplier or depot level of maintenance). In this case, all assemblies are designated as being repaired at the supplier’s facility, and each individual analysis is reviewed in terms of the criteria...to determine the possible effects associated with the single policy” (Blanchard, 2014).

“Finally, the output of the repair-level analysis must be reviewed to ensure compatibility with the initially specified system maintenance concept. The analysis data may either directly support and be an expansion of the maintenance concept, or the
maintenance concept will require change as a consequence of the analysis. If the latter occurs, other facets of system design may be significantly impacted. The consequences of such maintenance concept changes must be thoroughly evaluated before arriving at the final repair-level decision” (Blanchard, 2014).

Each of Blanchard’s recommendations is supported by this praxis with the exception of the second decision logic. This praxis recommends treating each analyzed component, unit, assembly, or task as an individual decision based on all analysis elements and not solely on the lowest-cost option. Blanchard’s first decision recommendation aligns with this logic and is most suitable for large engine maintenance programming. The second logic of choosing the overall lowest-cost resource for all items may default to a program with limited flexibility and increased risk.
Chapter 3. Research and Methodology

3.1 Research Questions

This research will answer several questions to inform a Level of Repair Analysis (LORA) for maintenance resource planning. These questions confront program sponsors, engineers, and operators in all phases of an asset’s life cycle. A thorough analysis will ultimately exist as a living process, iteratively asking and answering these questions to improve the constantly evolving logistics network supporting the asset. The analysis will identify the most cost-effective, responsive, and realistic maintenance resource.

This research will discuss why a LORA is an appropriate method for the task. LORA is prescribed by the Coast Guard and recommended by the Department of Defense. The Coast Guard prescribes LORA to determine the appropriate maintenance resource for a component, unit, or assembly. Depot maintenance is the true cost driver for the maintenance of complex systems such as those found on cutters. To determine which resource is most efficient for the completion of depot maintenance, we must analyze the economic and noneconomic costs and benefits of each resource.

Can a blend of resources be used to reduce life cycle costs and sustain Coast Guard technician proficiency? The service has learned through experience that a blend of internal (Coast Guard) and external (commercial) resources normally provides the most cost-effective and logistically viable maintenance program. However, the Coast Guard has not predicted this result through analyses. This research will investigate this possibility.

Can the organization establish a better maintenance philosophy? The answer, of
course, is always “yes”. This research will outline a means of doing so.

3.2 Research Objectives

The goals of this praxis include:

- Develop a LORA model influenced by Activity-Based Cost Management theory to estimate the cost of maintenance.
- Perform an analysis of National Security Cutter propulsion engine maintenance resources to determine the balance of resources required to reduce life cycle costs and sustain Coast Guard technician proficiency.
- Develop procedures to execute these analyses during both acquisition and sustainment life cycle phases.
- Complete a case study of the Famous Class Medium Endurance Cutter propulsion diesel engine to apply the model to an asset in the sustainment life cycle phase.

3.3 Methodology

This praxis proposes the model depicted in Figure 3-1, Level of Repair Analysis Model. LORA and Business Case Analysis (BCA) elements of a Life Cycle Cost Analysis (LCCA) serve as the foundation for the model. The methodology supports an Activity-Based Cost Management (ABC/M) approach to estimating the costs of each alternative by focusing on individual maintenance task costs and the impact of their sum on selecting a maintenance program. The model will provide a rigorous analysis of maintenance resource alternatives (Coast Guard technicians, non-Coast Guard technicians, and a blended team) through the analysis of noneconomic and economic resource elements. The noneconomic analysis of logistics elements informs the subsequent economic analysis. The economic analysis develops cost estimates for labor
rates, tools, training, supplies, and facilities. The labor rates convey Maintenance Cost per Manhour (MCPMH) for each available resource. The economic analysis data can provide analysts with the estimated minimum, maximum, and mean resource costs for each maintenance task or the entirety of the maintenance program. The LORA will produce usable data for decision and sensitivity analyses which will subsequently inform a maintenance philosophy, short and long-range maintenance plans, the Integrated Logistics Support Plan (ILSP), commercial resource contracts, Maintenance Augmentation Team staffing plans, and sustainment logistics resource allocations (e.g. training, supply chain management, and Product Line processes).

The decision analysis will present qualitative and quantitative outputs for the development of a strategic resourcing decision. The sensitivity analysis will enable analysts to determine if changing the value of an independent variable will impact the analysis. Figure 3-1 is further decomposed in sections 3.7 - 3.10 of this Chapter.
3.4 Data Collection and Analysis

Data is obtained from multiple units within the Coast Guard Naval Engineering organization which maintain all vessels in sustainment. None of the data collected in the course of this research is classified or deemed sensitive.

Maintenance data of particular interest to this praxis includes manufacturer-prescribed maintenance tasks, quantitative maintenance performance data reported by maintenance centers, and technical support information. This information includes maintenance task duration, frequency, technician traits (quantities and qualification levels), procedures, tools, and parts. For economic analysis, Coast Guard technician costing data will include a Maintenance Augmentation Team personnel allowance list and standard personnel costs. These costs will be compared to the cost of similarly qualified non-Coast Guard technicians derived from current service contracts.

Policies, plans, and publications which influence maintenance planning are critical to this praxis. In the case studies, Coast Guard Integrated Logistics Support Plans (ILSPs), maintenance process guides and reports issued by the Surface Forces Logistics Center (SFLC), and training system standard operating procedures will provide qualitative & quantitative data for noneconomic and decision analyses.

3.5 Hypothesis

An enhanced blend of maintenance resources will favor internal Coast Guard technicians over contracted maintenance resources.

3.6 Model Validation

Model validation will be achieved by analyzing the main propulsion diesel engine for assets in acquisition and sustainment life cycle phases. The National Security Cutter
(NSC) case study will serve as the acquisition application, and the Medium Endurance Cutter (MEC) case study will serve as the sustainment application. Applying the model to multiple vessel types will change class-specific variables including maintenance requirements, philosophy, vessel deployment periods (drives availability for maintenance), equipment manufacturer and configuration, and the costs and schedules associated with Coast Guard and non-Coast Guard maintenance technicians.

### 3.7 Noneconomic Analysis

The noneconomic analysis consists of logistics elements that influence an organization’s ability to complete maintenance tasks. These elements include workforce proficiency, maintenance philosophy, tools, environment, organization policies, support contracts, training, supply chain, and facilities. The noneconomic analysis produces outputs that directly impact the economic and decision analyses.

It is imperative that analysts gather reliable extant data to inform their work. During the acquisition phase of an asset’s life cycle, the organization will procure extant data from manufacturers in the form of technical drawings, repair manuals, service bulletins, and specification sheets. Acquiring data in sufficient detail is particularly important. Analysts will require task data that prescribes task duration, complexity, frequency, and required skill levels. Analysts will also require maintenance schedules and detailed parts lists. Ideally, parts lists will include prices and quantities per unit. Once the asset has transitioned into the sustainment life cycle phase, performance data should be obtained from maintenance managers to inform subsequent LORAs.

Analysts can identify the organization’s environment by obtaining maintenance program policies, procedures, resource lists, and strategies. These elements produce a
picture of the organization’s maintenance culture, guide the management of programs, and enable analysts to align their work with the expectations of leadership. Viewing the analysis through the organization’s lens will enable the analyst to develop a product that aligns with the organization’s business model(s), strategic vision, and resources.

The analyst must also determine whether the organization’s technicians possess the technical proficiency in repairing or replacing the component in question. The analyst can evaluate the organization’s historical approach to maintaining similar systems and the degree of technical acumen possessed by technicians. Analysts will review training programs, technician qualification or certification levels, and maintenance tasks for similar equipment to determine the current level of internal workforce proficiency. These levels can subsequently be compared with the proficiency requirements of the newly procured equipment. For example, if a new pump is purchased for a piping system, the analyst can determine if technicians internal and external to the organization possess the training and experience required to maintain the pump. To do so, the analyst can ascertain the level of technical qualification or certification recommended by the manufacturer and determine whether the technicians above possess those qualifications or certifications.

The identification of required skills is very important to determining whether resources exist and capturing their associated costs. For example, a task may not require a definitive qualification or certification but may simply require a technician possess the basic mechanical skills needed to replace the pump as opposed to the more advanced technical skills required to rebuild the pump. The former technician requires minimal training and experience whereas the latter technician requires advanced training and specific experience.
Acquisitions professionals should work with equipment suppliers to identify the tools required to perform asset maintenance. General tools, such as basic hand tools, and special tools, such as those designed solely for a specific piece of equipment, are critical to a maintenance program’s success and the analysis of their availability and cost is critical to the LORA. Special tools may only be available in limited quantities and from select vendors so their impact on the readiness and cost of a maintenance program should be captured as early in the analysis as possible. It is important to capture the correct cost for special tools as they may be provided at a lower cost when purchased in bulk during an acquisition. When capturing risks, logisticians should also consider whether special tools have long lead times, diminishing supply quantities, and redesign periodicity concerns.

In the development of a maintenance philosophy, logisticians should consider the existence of, or opportunity to establish, maintenance support contracts. Particularly in the early years of an asset’s life cycle, it may be necessary to depend heavily upon external resources (suppliers or manufacturers) for maintenance. Systems of high complexity or proprietary design may require more contracted maintenance support than systems of more simple or common design. Every effort should be made to identify the economic and noneconomic impacts of using support contracts. During the noneconomic analysis, it is important to capture contract details including labor rates, technician proficiency levels, the provision of materials (parts, tools, and consumables), travel agreements, and contract duration. This information will provide qualitative data for the comparison of internal and external maintenance resources and inform the subsequent economic analysis.
Training resources play a significant role in the determination of maintenance resourcing. To develop proficiency, technicians require training and experience. Many organizations provide formal training programs to develop both general trade and advanced technical skills. Organizations may employ internal training resources, establish training contracts with industry providers, obtain manufacturer-hosted training, or utilize a blend of these options. The noneconomic analysis will document what training is required to support the maintenance philosophy and what resources are available to provide training. Specifically, the analysis should capture the status of training facilities, aids, staff, curriculum, and materials. Training costs will be estimated in the economic analysis.

The Noneconomic Analysis Form found in Table 3-1 guides users through the process of recording essential noneconomic data. The process starts with listing the component title and assigning a serial number. The component title reflects the equipment’s common name. The Task Title and Task Number can be used if the organization manages an Activity-Based Cost Management program or prefers to analyze maintenance tasks versus components. There is value in analyzing maintenance tasks versus components in cases where manufacturers provide comprehensive maintenance programming, and the organization wishes to understand the cost of each maintenance activity. The National Security Cutter and Medium Endurance Cutter case studies found in Chapter 4 provide examples of analyses based on maintenance tasks versus components.

The first question posed by the Noneconomic Analysis Form asks if the component failure will inhibit equipment operation. Asking this question helps assess the risk
associated with repair efforts, the impact of failure on equipment operating status, and whether the component should be repaired or discarded. If the component failure has no impact on safe operations, the risk of discarding the item, or the pressure to quickly restore the equipment to operation, may be low. The reduction of risk and concern removes the motivation to fund costly short-term repairs. In instances where component failure inhibits equipment operation, the analyst must communicate the impact to vessel readiness and the estimated cost of repair per resource.

As previously noted, analysts must determine if the original equipment manufacturer prescribes a comprehensive maintenance program and how the program aligns with the organization’s maintenance philosophy. Each task should be analyzed for task duration, frequency, and required technician traits (quantities and qualification levels). The organization will be unable to perform tasks if they exceed the capability of the internal workforce. Support contracts can be initiated to address these shortfalls by building internal workforce proficiency through training or by assigning highly complex tasks to original equipment manufacturers or advanced industry technicians.
Table 3-1: Noneconomic Analysis Form

<table>
<thead>
<tr>
<th>Component</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component ID:</td>
<td>001</td>
</tr>
<tr>
<td>Task Title (ABC/M option):</td>
<td>-</td>
</tr>
<tr>
<td>Task Number (ABC/M option):</td>
<td>-</td>
</tr>
<tr>
<td>Gather extant data sources</td>
<td></td>
</tr>
<tr>
<td>1 Does component failure inhibit equipment operation?</td>
<td>Y</td>
</tr>
<tr>
<td>2.a. Does equipment manufacturer or CG recommend PM task(s)?</td>
<td>Y</td>
</tr>
<tr>
<td>2.b. Does the complexity of the task(s) exceed D-level maintainer competency?</td>
<td>Y</td>
</tr>
<tr>
<td>2.c. What is the estimated task duration in total hours?</td>
<td>102.9</td>
</tr>
<tr>
<td>2.d. What level technicians are required? (circle applicable)</td>
<td>Basic</td>
</tr>
<tr>
<td>2.e. How many technicians are required per qualification level?</td>
<td>4</td>
</tr>
<tr>
<td>2.f. Do any existing support contracts cover the task?</td>
<td>Y</td>
</tr>
<tr>
<td>2.g. How does the task align with the organization's maintenance philosophy?</td>
<td>D</td>
</tr>
<tr>
<td>3 Does maintenance technical information exist?</td>
<td>Y</td>
</tr>
<tr>
<td>4 Is the component available through the organization's supply chain?</td>
<td>Y</td>
</tr>
<tr>
<td>5 Are special tools required and available?</td>
<td>Y</td>
</tr>
<tr>
<td>6 Are depot maintenance facilities required and available?</td>
<td>Y</td>
</tr>
<tr>
<td>7 Does the component present environmental impacts?</td>
<td>Y</td>
</tr>
<tr>
<td>8.a. Do designated technicians exist in the organization?</td>
<td>Y</td>
</tr>
<tr>
<td>8.b. Do qualified technicians exist in the industry (OEM or equivalent)?</td>
<td>Y</td>
</tr>
<tr>
<td>8.c. Is training to develop technician competency available?</td>
<td>Y</td>
</tr>
</tbody>
</table>

Upon completion of the noneconomic analysis, qualitative data will be organized for future use in the decision and risk analyses. Quantitative data associated with noneconomic analysis elements will be recorded for use in the economic analysis described in Section 3.8 of this Chapter.
3.8 Economic Analysis

The economic analysis consists of cost elements that impact an organization’s ability to complete maintenance. These costs are associated with labor (internal and external technicians), tools, support contracts, training, supply chain, and maintenance facilities. After performing an economic analysis for each assembly, component, or task, proceed to the decision and risk analyses.

Labor costs are often the most influential element of economic analysis. They have a significant impact on determining the most cost-effective resource and level of maintenance completion. When capturing labor costs, every effort should be made to calculate the fully burdened rate of technicians in order to convey the true cost of labor to an organization. It is important to identify if the organization has a standard means of calculating the fully burdened rate of their personnel. For example, the Coast Guard’s Standard Personnel Cost (SPC) used in Chapter 4’s case studies accounts for pay, allowances, the Coast Guard’s share of the Federal Insurance Contribution Act (FICA), Social Security credits, and other expenses associated with compensating military personnel (USCG FY17 Congressional Justification, page CG-OE-9). The praxis case studies focus heavily on comparing the labor rates of Coast Guard (internal) and non-Coast Guard (external) technicians by using Coast Guard SPC and original equipment manufacturer labor quotes. Lastly, it is recommended that labor is measured at an hourly rate to align with maintenance hours. Doing so enables the analyst to calculate the cost of various quantities of maintenance performed by labor sources.

Training costs are a critical component of economic analysis. Internal or external resources can develop professional training programs. For new capabilities, training
startup costs normally fund a front-end analysis, training aid and facilities procurement, and curriculum development. Course development costs are normally a one-time investment whereas recurring training costs are required to host multiple course convenings. Recurring training costs may include student tuition (if applicable), travel, lodging, and course consumables. Leadership may choose to hire industry training providers should professional training resources not exist within the organization. Choosing an external provider can reduce the infrastructure, staffing, and material costs associated with managing internal programs. However, possessing internal training programs can provide unmatched change management flexibility, provide the organization with the ability to develop maintenance Centers of Excellence, and reduce the overall cost of training through logistics efficiencies. Ultimately, LORA estimates the impact of training costs imposed by potential maintenance resources and serves as one of many analyses for the determination of training needs.

Facility costs include those costs associated with the construction, maintenance, and operation of structures supporting maintenance activities. Technicians may work in industrial facilities in the execution of their duties regardless of whether they are internal or external to the organization. In some cases, a new facility will be established to support an acquisition and the costs of doing so will increase the overall cost of completing depot maintenance. In other cases, existing facilities may be repurposed to support the new maintenance program, resulting in much lower cost. In these instances, facilities may be considered sunk costs. The analyst may also need to account for energy costs depending upon how the organization treats utility funding. Many of the government’s entities do not track energy costs associated with individual buildings.
located on a large campus and therefore have created standard cost estimating practices to support analyses such as these. Analysts should use these standard estimating means to determine the impact of facility energy costs on the LORA. When estimating external resources, facility costs may already be included in the fully burdened rate of technicians. This assumption will require validation if not communicated in contract documentation.

Supply chain costs which may influence the LORA include procurement, transportation, handling, and inventory costs. It is recommended that an item’s unit price be considered separately from remaining supply chain costs to provide the most flexible cost estimation and establish a baseline procurement cost. Logisticians will document the impacts of existing organizational processes, geography, and procurement law in the noneconomic analysis and capture their costs in the economic analysis. Analysts can obtain these costs from existing service or supply agreements, independent price quotes, internal price estimates, or marketing publications (catalogs). In some analyses, the supply chain costs may be fixed and identical between maintenance providers, especially when the original equipment manufacturer is the only authorized provider of supplies. In other instances, costs may vary greatly and present drastically different availability and budget demands for an item. This is especially true when an item is available from multiple sources in various locations and quantities.

Disposal costs are those costs associated with retiring an item from service. Blanchard addresses material recycling/disposal factors as “The logistics activities during the system retirement and material recycling/disposal phase of the life cycle include (1) the processing of obsolete items out of the inventory, (2) the recycling of obsolete material for other uses, and (3) the decomposition and disposal of material that cannot be
utilized for other purposes.” (Blanchard, 2004)

Analysts should determine the focus of their LORA before calculating disposal costs. A LORA focused on components, assemblies, or units will consider the costs described by Blanchard whereas LORAs employing Activity-Based Cost Management may limit disposal costs to those associated with the completion of one iteration of a task. In the former instance an organization may focus on the budgetary impacts that an engine component may have on the overall supply chain (e.g., disposal of large inventory and the cost of managing disposal support contracts). In the latter instance the organization may attempt to capture the budgetary impact of completing an individual maintenance task and the logistics costs associated with that task.

<table>
<thead>
<tr>
<th>Economic Analysis Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item cost</td>
</tr>
<tr>
<td>Labor rates</td>
</tr>
<tr>
<td>Special tools cost</td>
</tr>
<tr>
<td>Supply, transport, and handling cost</td>
</tr>
<tr>
<td>Training development cost</td>
</tr>
<tr>
<td>Recurring training cost</td>
</tr>
<tr>
<td>Maintenance facility cost</td>
</tr>
<tr>
<td>Technical information cost</td>
</tr>
<tr>
<td>Disposal cost</td>
</tr>
<tr>
<td>Total estimated cost</td>
</tr>
</tbody>
</table>
3.9 Decision and Qualitative Risk Analysis

The decision analysis considers outputs of the non-economic and economic analysis for the development of a strategic maintenance plan. The proposed model uses a series of questions to guide decision makers toward an understanding of organizational impacts and risks. Table 3-3 contains an example of questions focused on program cost, the existence of support elements (e.g., supply chain, maintenance resources, and training), identification of life cycle phase, status of commercial resources (e.g., technicians, OEM parts supplies, overhaul facilities, and training), and knowledge management elements (technical information, technician proficiency, and tacit knowledge) which inform leadership in the development of the maintenance philosophy.

Table 3-3: Decision Analysis Form

<table>
<thead>
<tr>
<th>Decision Analysis Form</th>
<th>1</th>
<th>Is the cost of maintenance acceptable?</th>
<th>Y/N</th>
<th>Y-good</th>
<th>N-bad</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Are support elements in place to ensure success?</td>
<td>Y/N</td>
<td>Y-good</td>
<td>N-bad</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Is the proposed maintenance appropriately funded?</td>
<td>Y/N</td>
<td>Y-good</td>
<td>N-bad</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>What life cycle phase is the asset in?</td>
<td></td>
<td>Acquisition, sustainment, or disposal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Do non-organizational resources have the capacity to meet the demand?</td>
<td>Y/N</td>
<td>Y-good</td>
<td>N-bad</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Are external maintenance resources satisfactorily responsive?</td>
<td>Y/N</td>
<td>Y-good</td>
<td>N-bad</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Does the organization have the capability to complete the maintenance tasks?</td>
<td>Y/N</td>
<td>Y-good</td>
<td>N-bad</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Does the maintenance demand meet operational requirements?</td>
<td>Y/N</td>
<td>Y-good</td>
<td>N-bad</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>What is the lowest estimated maintenance cost?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>What is the highest estimated maintenance cost?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>How do the analyses impact the existing ILSP?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>What is the most undefinable cost at this point?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

37
The Decision Analysis Form starts by asking whether the maintenance cost is acceptable. Costs will be considered acceptable if they do not exceed budget allocations. Answering the question “No” implies that the maintenance does not pose budgetary risks whereas answering the question “Yes” provides leadership with ability to determine whether additional financial resources should be provided to support the task, if cost savings can be realized by further investigating economic elements, and whether changes should be made to the maintenance plan to reduce costs without degrading operational readiness.

The second question asks if support elements are in place for a successful maintenance program. Answering “No” implies that one or more maintenance support elements from the noneconomic analysis are negatively impacting the program. For example, it will be difficult to establish an effective maintenance program if the supply chain cannot meet demands, if internal or external technicians are unavailable, if training does not exist, or if maintenance facilities cannot be developed. Answering “No” implies that these obstacles may not be easily overcome without significant investment.

Asking if the proposed maintenance is appropriately funded provides leadership with a different funding consideration than that posed by the first question regarding whether the cost is acceptable. Answering “No” implies that the financial demand of the required maintenance plan is justified but that the organization has yet to fund the program properly. Answering “No” presents leadership with the opportunity to acknowledge that the maintenance program is properly designed yet improperly resourced.

Next, the analyst will identify the program’s current life cycle phase. It is possible for an asset to exist in one or both phases of the life cycle. For example, a class of ships may
exist in both acquisition and sustainment phases when ships are operating in the field (sustainment) while new ships of the same class are being constructed (acquisition). The long lead time associated with building a large asset increases the probability of this occurrence. In some cases, assets that are procured and rapidly delivered (e.g., commercially available automobiles and boats) may immediately enter the sustainment phase upon purchase. When an asset exists in the acquisition phase, decisions regarding the funding and design of maintenance may reside with leadership in both acquisitions and sustainment areas of the organization. It is important to note that different life cycle phases may present different external support contracts, funding streams, and organizational impacts. Large acquisitions may fund comprehensive support contracts to reduce demands on existing infrastructure in the early years of a life cycle. These contracts are often tied to warranties that are established to bridge the support gap until sustainment resources are developed or responsible for maintenance.

Determining whether internal and external maintenance resources have the capacity to meet demands without impacting readiness occurs next. The mere existence of resources does not make them suitable options for strategic maintenance planning. The availability and skill capacity of each resource should be captured in the noneconomic analysis. It can be difficult to determine the scope of these demands if the LORA is being completed in acquisitions due to a lack of historical system performance data and limited availability of detailed extant data. However, analysts can establish baseline expectations by assessing the original manufacturer’s prescribed maintenance program and relaying those demands to all resource providers during the collection of extant data. The analysis of resource capacity should include an assessment of the resource’s expected response
time to corrective maintenance tasking, a count of the available technicians at each skill level, an understanding of contract and service level agreement limitations, and an account of the tools and facilities available to the resource upon tasking.

Total equipment maintenance demand is a key factor in assessing risk and formulating strategic decisions. The LORA provides an opportunity for leadership to plan maintenance periodicities within the confines of designed operating tempo. The maintenance philosophy must align with the operating requirements of a system, especially in situations where extensive maintenance and frequent and arduous operations coexist. The more operating time is planned for an asset, the less opportunity exists for maintenance scheduling. Therefore it is imperative that decision makers understand the impact that maintenance activities have on the operational readiness of an asset. Another important aspect of maintenance availability is frequency. A maintenance program may be ineffective if it requires low duration but high-frequency interruptions for an asset that is designed for consistent operation. This is only one example of how maintenance demands may not meet operational requirements.

The ability to estimate the lowest and highest maintenance costs provides leaders with an understanding of potential best and worst case financial scenarios. Analysts will review the cost of each resource for each maintenance task and determine the lowest and highest estimated resource cost. They can conduct a breakeven analysis of each task to determine how much flexibility exists for each resource, assess the financial risk associated with one resource over others, and decide when one resource is the most cost-beneficial option. Of course, money does not tell the whole story, and final resource selection should be made considering all aspects of the LORA, not just the lowest price.
option. It is also critical for decision makers to ask themselves if an unstable cost factor exists in the analysis. Leadership should be made aware if analysts determine that a particular element of the economic analysis has uniquely low confidence or high uncertainty. These conditions may alter the risk tolerance and decision methods chosen by leadership.

Finally, the impact of the proposed maintenance philosophy on the Integrated Logistics Support Plan (ILSP) should be considered. The first version of an ILSP is developed during the acquisition phase, a period where planning is paramount and historical data is yet to be captured. The decisions made during the completion of the acquisition phase LORA inform the initial maintenance philosophy, establish logistics plans, and determine the split of maintenance tasks between O-level and D-level resources. ILSP revisions can benefit from iterative LORAs that are updated based on renewed maintenance performance data from the field. As the asset moves further through sustainment, other logistics planning events occur which influence LORA and therefore impact the ILSP. For example, the Coast Guard completes Maintenance Effectiveness Reviews (MER) throughout a cutter’s life cycle which will be introduced as extant data for the next LORA. The LORA may produce different decisions for the ILSP after considering the MER’s impacts. Additionally, the validation of maintenance procedures, exercise of the supply chain, and success or failure of support contracts can collectively or independently influence LORA outputs and the subsequent revision of the ILSP. Upon, completion of the decision analysis, leaders will be responsible for making ILSP decisions which translate the LORA’s outputs into actionable plans.
3.10 Sensitivity Analysis

Sensitivity analysis enables analysts and decision makers to determine if changing the value of an independent variable will impact the analysis. A task with close resource costs may require more consideration for the development of a final decision. Analysts can change an applicable value and evaluate the quantitative and qualitative impacts (e.g., cost, schedule, or quality) on program success when there is a healthy measure of uncertainty or variation in data or resource capability. Decision makers may alter particular variables to test outcomes in cases of multiple probabilities of resource success. For example, analysts may note that a particular task presents multiple probabilities of duration based on unpredictable yet possible interferences such as seized fasteners (e.g., bolts, screws, or rivets), supply delays (e.g., damaged or delayed supplies) or damaged insulation. Although these conditions present uncertainty, it is possible to estimate their impact on the duration of a task which ultimately impacts labor costs. After evaluating the impacts, analysts can present their findings and recommendations to decision makers.

Basten (2008) acknowledges fixed and variable costs for resources, most importantly working hours of service technicians. Technicians may experience work delays induced by parts lead times, poor equipment condition, parts discrepancies, or environmental alterations (e.g. space configuration, weather, and geography). This is relevant to a focus on labor rates for sensitivity analysis. This praxis proposes developing a one-way sensitivity graph to analyze the impact of various task durations on maintenance program labor costs per resource. During the one-way sensitivity analysis, analysts vary one input while all other inputs are held constant at a base value (Clemen and Reilly, 2014). Various program labor costs can calculated by multiplying economic analysis labor costs
for each resource by task duration multiples of .08, 1.0, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, and 3.0.

\[ \text{total labor cost} \times \text{task duration multiplier} = \text{alternate program labor cost} \]  

(3.1)

After calculating various program labor costs, analysts can assess the financial risks associated with overwork for each resource. A scale of (.08) – (3.0) was determined appropriate after studying Medium Endurance Cutter maintenance performance data for the year 2017. While this praxis focuses on applying the one-way sensitivity analysis to total resource labor costs (i.e., sum of all maintenance tasks), the same method can be used to analyze costs on a more granular level for each individual maintenance task if so desired. Another means of viewing sensitivity with task-level granularity is to analyze breakeven ratios. To determine the breakeven ratio for two resources, analysts can divide the estimated total labor cost of one resource by the other.

\[ \frac{\text{resource 1 total labor cost}}{\text{resource 2 total labor cost}} = \text{breakeven ratio} \]  

(3.2)

After calculating the breakeven ratios, analysts can identify high and low financial risks between two resources for all tasks. High ratios show the greatest cost disparity between two assessed resources. These tasks are a good starting point for resource selection as they pose the highest financial risk. However, it is highly discouraged to make resource selections based solely on estimated costs. Noneconomic factors must be weighed prior to understanding the risk associated with each selection.

Low ratios indicate little difference between estimated labor costs and provide leverage for strategic resource decisions based on total program risks. In most cases, the selection for low ratio tasks will default to the organization’s resources in order to realize the highest return on internal resource investments and free external resources for their
dedicated tasks. This method may also provide schedulers with healthier resource environments as buffer periods will be less constrained for complex tasks and availability improved for unplanned maintenance events (corrective).
Chapter 4. Results

The Level of Repair Analysis outlined in Chapter 3 is applied to two Coast Guard cutter classes in the following case studies. The National Security Cutter (NSC) case study applies the model to a program in acquisition, and the Medium Endurance Cutter (MEC) case study applies the model to a program in sustainment. A LORA has not been published for the NSC and has not been previously completed for the MEC. Conducting a LORA for both programs provides immediate value to Coast Guard maintenance planners.

The NSC program currently exists in multiple life cycle phases. New NSCs are being constructed in the acquisitions phase while commissioned NSC are operating in the sustainment phase. The high cost of NSC propulsion engine maintenance related to continued dependency on the original equipment manufacturer for depot maintenance is the motivation for this research. The MEC program currently exists solely in the sustainment phase. A mature maintenance program with strong Coast Guard and commercial maintenance resourcing provides an excellent platform for the validation of the proposed model. The existence of dependable depot maintenance completion data provides a view of Coast Guard Maintenance Augmentation Team (MAT) performance in support of cutter propulsion engines. A MAT is the home of Coast Guard shoreside depot maintenance providers including Machinery Technicians (MKs) and Electrician Mates (EMs).

4.1 Case Study Assumptions

The following assumptions apply to both the NSC and MEC case studies. They are
based on Coast Guard policies and similarities to both case studies.

4.1.1 Labor Rate Calculations

A realistic determination of resource labor rates is a critical factor in the economic analysis. This praxis presents labor rates for two maintenance resources, Coast Guard technicians and non-Coast Guard technicians. Coast Guard technicians are specifically identified as members of a Maintenance Augmentation Team. In the case of the NSC, non-Coast Guard technicians are solely contracted employees of the propulsion engine manufacturer. In the case of the MEC, non-Coast Guard technicians are either employees of the propulsion engine manufacturer or an expert marine mechanic on an existing support contract.

This praxis applies several assumptions to all maintenance resources. It assumes that all technicians are available for 1579.49 annual work hours (Productive Time per Year) in accordance with the Coast Guard Staffing Logic and Manpower Analysis Requirements Manual, COMDTINST M5310.5. This is the Peacetime Military Ashore 40-hour Workweek where regular workweeks consist of five work days a week of varying length (8- or 10-hours) and are calculated as $(40 - 5.86 - 3.87) \times 52.18 = 1579.49$. A support unit’s Productive Time per Year is calculated as:

$$\text{day work hrs/week} \times 52.18 \text{ weeks} = \text{Productive Time per Year} \quad (4.1)$$

Coast Guard technician labor rates are calculated using the Coast Guard’s Standard Personnel Cost (SPC) as a baseline. SPC is unique to the military rank of a technician, and each technician possesses a level of technical proficiency comparative to that of a non-Coast Guard technician. For example, Second Class (MK2/E5) and First Class (MK1/E6) Machinery Technicians are equivalent to non-Coast Guard Basic Technicians
and Chief (MKC/E7) and Senior Chief (MKCS/E8) Machinery Technicians are equivalent to non-Coast Guard advanced technicians. The annual SPC for each technician of each rank is then summed and averaged to create a composite labor rate for basic and advanced technicians. Third Class Machinery Technicians (MK3/E-4s) are considered Journeymen level technicians (below basic) and therefore are not provided advanced MTU engine training. However, they assist basic and advanced technicians during depot maintenance to acquire critical on-the-job training (builds proficiency) and reduce labor for basic and advanced technicians. For this analysis, E4s are assigned the same composite labor rate as basic technicians. This prevents Coast Guard labor estimates from being unfairly reduced since all task estimates require basic or advanced technicians.

Table 4-1: Coast Guard Labor Rates

<table>
<thead>
<tr>
<th>Rank</th>
<th>Standard Personnel Cost</th>
<th>Base Hour Rate</th>
<th>Basic Tech E5-E6</th>
<th>Advanced Tech E7-E8</th>
<th>Advanced Tech GS13</th>
</tr>
</thead>
<tbody>
<tr>
<td>E4</td>
<td>$78,746.00</td>
<td>$49.86</td>
<td>$71.00</td>
<td>$86.17</td>
<td>$100.40</td>
</tr>
<tr>
<td>E5</td>
<td>$92,250.00</td>
<td>$58.40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E6</td>
<td>$104,339.00</td>
<td>$66.06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E7</td>
<td>$116,690.00</td>
<td>$73.88</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E8</td>
<td>$127,823.00</td>
<td>$80.93</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CWO</td>
<td>$152,511.00</td>
<td>$96.56</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCDR</td>
<td>$164,708.00</td>
<td>$104.28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GS13</td>
<td>$153,732.00</td>
<td>$97.33</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Assumptions**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Work Hours</td>
<td>1579.49</td>
</tr>
<tr>
<td>Personnel Allowance (PAL)</td>
<td>34</td>
</tr>
<tr>
<td>CG Overhead</td>
<td>$8.77</td>
</tr>
<tr>
<td>GS13 Overhead</td>
<td>$3.07</td>
</tr>
</tbody>
</table>

*Considers LCDR as overhead*

The number of technicians available for maintenance tasking is determined by the number of technicians assigned to a Maintenance Augmentation Team’s (MAT) Personnel Allowance List (PAL). The MAT Alameda PAL is used as the foundation for
this analysis and contains 34 technician billets. This number impacts the determination of a Coast Guard Overhead Rate which for the sake of this analysis is determined to be $8.77 per hour. The Coast Guard Overhead Rate is added to each composite labor rate to reflect the cost of a Chief Warrant Officer (CWO), a Lieutenant Commander (LCDR), and a General Schedule 13 (GS13) being assigned to supervisory and administrative roles in the organization. This rate was derived using the following equation:

\[
\frac{($96.56 + $104.28 + $97.33)}{34} = $8.77
\]  

(4.2)

The labor rates were calculated using the following data:

<table>
<thead>
<tr>
<th>Description</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team Labor Hours are hours per component / number of technicians</td>
<td></td>
</tr>
<tr>
<td>Coast Guard Labor Hours are the number of hours per technician rank</td>
<td></td>
</tr>
<tr>
<td>Coast Guard Labor Cost per Hour is the cost per CG technician rank per hour</td>
<td></td>
</tr>
<tr>
<td>Coast Guard Total Labor Cost: sum hourly labor rate for a CG maintenance team to complete the maintenance task</td>
<td>( \text{Team Labor Hours} \times \text{Coast Guard Labor Cost per Hour} )</td>
</tr>
<tr>
<td>Non-Coast Guard Total Labor Cost: sum hourly labor rate for a Non-CG maintenance technician to complete the maintenance task</td>
<td>( \text{Team Labor Hours} \times \text{Non-Coast Guard Labor Cost per Hour} )</td>
</tr>
</tbody>
</table>

Table 4-2 lists labor rates for non-Coast Guard technicians. The current technical service rates are provided by each source annually or upon contract renewal. MTU rates are listed on the company’s Price List for Marine Technical Services 2017, ALCO technical representative and Fairbanks Morse advanced technician rates are agreed upon through existing contracts.
The Coast Guard Reliability Program Process Guide defines three types of maintenance: Planned (Scheduled) Maintenance, Unplanned (Unscheduled) Maintenance, and New Work. MPCs are planned maintenance (CD, TD, or FF), and corrective maintenance tasks are unplanned maintenance. These maintenance types align with the Coast Guard’s Bi-Level Maintenance philosophy which divides all tasks into either organizational (O-level) or depot (D-level) types as depicted in Figure 4-1. The determination of maintenance level drives resource options with O-level tasks primarily being the responsibility of the cutter crew and D-level tasks assigned to Maintenance Augmentation Teams, non-Coast Guard technicians (contractors), Industrial Production Facilities (IPF) or Detachments (IPD), or the Advanced Ship System, Instruction, and Support Team (ASSIST).

<table>
<thead>
<tr>
<th>Non-Coast Guard Technician Hourly Rates</th>
<th>National Security Cutter Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTU Senior Technician</td>
<td>$280.00</td>
</tr>
<tr>
<td>MTU Mechanical/Electrical Tech</td>
<td>$187.00</td>
</tr>
<tr>
<td>MTU Engineer</td>
<td>$230.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Famous Class Medium Endurance Cutter Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALCO Local Technical Representative</td>
</tr>
<tr>
<td>Fairbanks Morse Engine Advanced Technician</td>
</tr>
</tbody>
</table>

**MTU Overtime Notes:**

1. MTU overtime rate is 1.5 x hourly rate
2. Overtime charged any day exceeding 8 hours and all day Saturday
3. Overtime charged is 2 x the hourly rate on Sundays and holidays, including one day before and after a holiday, with a minimum of 4 hours per day
4.2 National Security Cutter Level of Repair Analysis

The National Security Cutter (NSC) is the Coast Guard’s largest cutter designed for maritime homeland security, law enforcement, and national defense missions (USCG, ILSP, 2013). The NSC is 418 feet in length with a beam (width) of 54 feet and a draft of 22.5 feet and is designed to operate away from home port for up to 230 days a year with an optimally manned crew (USCG, 2013). The crew size reduces operating expenses and transfers most of the responsibility for maintenance to resources external to the cutter crew. On the date of this publication, there are ten hulls planned for the class with home ports in Alameda, CA, Charleston, SC, and Honolulu, HI.

Each home port has a Maintenance Augmentation Team (MAT) dedicated to the execution of cutter depot maintenance (D-level). The MAT is staffed to support D-level maintenance on the NSC’s various systems including the propulsion diesel engines. However, MAT technicians currently lack the training and experience required to
perform much of the maintenance they are purposed for. This situation has created a continued dependency on the original equipment manufacturer for the completion of preventative and corrective D-level maintenance. A LORA will determine whether the Coast Guard should dedicate more resources to the development of internal technical proficiency, continue its dependence on commercial technicians, or use a blend of these resources.

4.2.1 National Security Cutter Assumptions

Independent Variables:

• Maintenance procedures
• National Industrial Enterprise resources (Coast Guard technicians)
• Contract maintenance resources (non-Coast Guard technicians)
• Training resources (training availability, course types)

Dependent variables:

• Maintenance cost per man-hour (MCPMH) for Coast Guard technicians
• Maintenance cost per man-hour (MCPMH) for contracted technicians
• Life cycle sustainment cost projections
• Training cost projections
• Coast Guard technician proficiency (measured by the capability to perform specific maintenance tasks). Rating Performance Qualifications establish baseline technical proficiency requirements for Coast Guard technicians and are used to determine the appropriate level of a technician for task execution.
4.2.2 National Security Cutter Noneconomic Analysis

The original NSC LORA was completed by a Deepwater program acquisition contractor, Integrated Coast Guard Systems, LLC (ICGS). That LORA was completed solely for the use of ICGS and is not published in the repository of NSC logistics documents maintained by the Program. Therefore, this LORA will be the first LORA completed for the NSC’s propulsion diesel engine to inform the Integrated Logistics Support Plan (ILSP).

Extant data available for this LORA includes original equipment manufacturer maintenance schedules, existing Coast Guard Maintenance Procedure Cards (MPCs), training system data, and Surface Forces Logistics Center (SFLC) process guides. Of critical importance to the analysis is the current NSC Integrated Logistics Support Plan (ILSP). The ILSP serves as the master logistics planning document that describes “necessary logistic activities, assigns responsibility for those activities, and establishes a schedule for completion” (USCG, 2013). It is periodically updated throughout a program’s life cycle from acquisition through disposal. The current NSC maintenance philosophy is defined in the NSC ILSP, Section C: Supportability Elements (USCG, 2013).

National Security Cutter Noneconomic Analysis Form Completion

The NSC noneconomic analysis is completed using the Noneconomic Analysis Form described in Chapter 3. Table 4-3 shows the completed version of the form and precedes answers to each question.
Table 4-3: Sample NSC Propulsion Diesel Engine Noneconomic Analysis Form

<table>
<thead>
<tr>
<th>Noneconomic Analysis Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component:</td>
</tr>
<tr>
<td>Component ID:</td>
</tr>
<tr>
<td>Task Title (ABC/M option):</td>
</tr>
<tr>
<td>Task Number (ABC/M option):</td>
</tr>
</tbody>
</table>

1. Does component failure inhibit equipment operation? Y

2.a. Does equipment manufacturer or CG recommend PM task(s)? Y
2.b. Does the complexity of the task(s) exceed D-level maintainer competency? Y
2.c. What is the estimated task duration in total hours? 102.9
2.d. What level technicians are required? (circle applicable) Basic Advanced
2.e. How many technicians are required per qualification level? 4 2
2.f. Do any existing support contracts cover the task? Y
2.g. How does the task align with the organization's maintenance philosophy? D
3. Does maintenance technical information exist? Y
4. Is the component available through the organization's supply chain? Y
5. Are special tools required and available? Y
6. Are depot maintenance facilities required and available? Y
7. Does the component present environmental impacts? Y
8.a. Do designated technicians exist in the organization? Y
8.b. Do qualified technicians exist in industry (OEM or equivalent)? Y
8.c. Is training to develop technician competency available? Y

1. Does component failure inhibit equipment operation?

Answer: Yes.

Explanation: A loss of propulsion diesel engine component function requires the engine to be secured and repaired. The engine will be unavailable until O- or D-level
corrective maintenance is performed to restore the engine to operational status. While the engine is secured, the cutter is limited to using the other propulsion diesel engine or marine gas turbine for maneuvering. This is most impactful when mooring or unmooring the vessel in a port or while operating at sea during the execution of primary missions. This is least impactful while the cutter is moored in home port in a depot maintenance availability.

2.a. Does equipment manufacturer or CG recommend PM task(s)?

   Answer: Yes.

   Explanation: Both the Coast Guard and manufacturer prescribe preventive maintenance tasks. The Coast Guard built the engine’s MPCs from the manufacturer’s maintenance schedule. The maintenance cards are being validated by the Engineering Systems School at the Coast Guard Training Center as a part of the advanced technician course development project. MPCs were extracted from the Coast Guard Logistics Information Management System (CG LIMS) database and crosschecked against the MTU 20 V 1163 TB93 Maintenance Schedule (MTU, 2013).

   2.b. Does the complexity of the task(s) exceed D-level maintainer competency?

   Answer: Yes.

   Explanation: The MTU Maintenance Schedule assigns various qualification levels to all prescribed tasks (MTU, 2013). The depot maintenance tasks prescribed by Coast Guard MPCs were designed based on these recommendations and a comparison to the bi-level maintenance philosophy. The cutter crew is trained and staffed to complete Qualification Level 1 (QL1) preventive maintenance which is operational checks and
maintenance that does not require heavy component disassembly (MTU, 2013). Cutter crews may be tasked with completing some QL2 maintenance which is solely corrective maintenance requiring the replacement of a component (MTU, 2013). The Coast Guard assigns QL3 and QL4 maintenance as D-level maintenance with QL3 assigned to Coast Guard Maintenance Augmentation Teams (MATs) and QL4 tasks assigned to the original equipment manufacturer. MTU defines QL3 maintenance as those tasks that require partial disassembly of a product (MTU, 2013). Rating Performance Qualifications (RPQs) for E-5 and above Machinery Technicians and Electrician Mates provide the baseline technical skills needed to complete QL3 tasks. However, RPQs generally do not prepare Coast Guard technicians for diesel engine QL4 tasks as a center section or complete engine overhaul requires the highest level of model-specific training and production-level industrial facilities outfitted for the task. Therefore, all Coast Guard equivalent QL3 tasks became the focus of this analysis, and all other maintenance is automatically prescribed to cutter crews (QL1) or the manufacturer (QL4).

2.c. What is the estimated task duration in total hours?

Answer: 102.9

Explanation: The estimated task duration is shown in Table 4-4, NSC Preventive Depot Maintenance Procedure Task Data, as the sum of Team Labor Hours. The duration data prescribed for each applicable Coast Guard MPC is reported as Hours Per Component and Number of Technicians. The numbers are extracted from each MPC to determine Team Labor Hours in the following equation:

\[
\text{Hours Per Component} / \text{Number of Technicians} = \text{Team Labor Hours}
\]
Team Labor Hours indicate the total estimated time period a team of technicians will be onsite to perform a task. Once, all Team Labor Hours are identified, they are summed to estimate the Team Labor Hours required to complete all QL3 maintenance tasks one time.

Table 4-4: NSC Preventive Depot Maintenance Task Data

<table>
<thead>
<tr>
<th>Type</th>
<th>Asset Class</th>
<th>Title</th>
<th>MPC Number</th>
<th>Revision Date</th>
<th>Hours per component</th>
<th>Number of Techs</th>
<th>Team Labor Hours</th>
<th>E8</th>
<th>E7</th>
<th>E6</th>
<th>E5</th>
<th>E4</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPC</td>
<td>418-WMSL, 75 CYLINDER HEAD</td>
<td>M-C-2008</td>
<td>6/31/2017</td>
<td>12 5 2.40</td>
<td>1 1 1 1 1</td>
<td>0 1 1</td>
<td>0 0 1 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPC</td>
<td>418-WMSL, 75 32 INCH EXPANSION JOINT</td>
<td>M-C-2163</td>
<td>2/15/2017</td>
<td>16 3 5.33</td>
<td>0 0 0 1 2</td>
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<td>M-H-2905</td>
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<td>M-A-100G</td>
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</table>

Sum: 102.9

2.d. What level technicians are required? (circle applicable)

Answer: Basic and Advanced

Explanation: Basic technician training provides technicians with operator and O-level maintenance (QL1, some QL2) training. The real value of Basic training is equipment familiarization. Advanced training provides technicians with D-level maintenance (QL3) training. The analysis determines that all MAT technicians will require both basic and advanced training to be considered as a Basic technician since the baseline requirement for conducting QL3 maintenance (D-level) is advanced training. Advanced technicians require no further equipment-specific training but require more advanced trade skills and experience. Thus, the requirement for the higher military rank or equivalent industry qualification delineates the difference between advanced and basic level technicians.
2.e. How many technicians are required per qualification level?

Answer: 4 Basic and 2 Advanced Trained Technicians

Explanation: The number of technicians required per qualification level is based on the maximum number of each level technician required for a single task. Table 4-4, NSC Preventive Depot Maintenance Task Data, displays the number of technicians required for each maintenance task by the planned maintenance program. The analysis accounted for each task occurring independently. Therefore the stated requirement of four basic and two advanced level technicians is predicated on tasks occurring in series, not parallel. The LORA does not present an estimation of the optimal number of MAT technicians required to complete tasks on a routine basis. That determination occurs when the Coast Guard conducts a Manpower Requirements Analysis.

2.f. Do any existing support contracts cover the task?

Answer: Yes.

Explanation: The Coast Guard maintains a service contract with the original equipment manufacturer to provide depot maintenance support for systems in sustainment. Warranty support is also available for cutters operating within the acquisition and transition to sustainment phases. However, contract risks are visible as there is a limited OEM service technician pool nationwide.

One consideration of this LORA is whether the existing support model of non-Coast Guard technician dependency is a fiscally responsible option. That determination will be made in the decision analysis.
2.g. How does the task align with the organization's (Coast Guard's) maintenance philosophy?

Answer: The NSC ILSP prescribes a maintenance philosophy that complies with the Coast Guard’s Bi-Level Maintenance Model which divides all maintenance into either Organizational (O) or Depot (D) levels. The ILSP states that “O-level maintenance is maintenance that is within the expertise of the crew and which the crew has the necessary tools and the authority to perform. D-level maintenance is material maintenance or repair requiring the overhaul, upgrading, or rebuilding of an asset or its components, assemblies, or subassemblies. D-level maintenance requires the highest level of maintenance capability, particularly that which is beyond the workload capacity of the crew” (USCG, 2013).

The manufacturer designed, and the Coast Guard adopted, a comprehensive maintenance program to support engine performance and reliability. The repair or discard decision for NSC propulsion engine parts defaults to “repair” since all parts are required for proper engine function. This LORA is thus focused on determining the level of repair at which the maintenance task will be completed. When aligning the manufacturer’s maintenance program with the Coast Guard’s bi-level maintenance philosophy, Qualification Level 1 (QL1) tasks conform to Coast Guard O-level maintenance and Qualification Level 3 (QL3) and 4 (QL4) tasks conform to D-level maintenance. D-level maintenance must be completed by advanced technicians found at Coast Guard Maintenance Augmentation Teams (MATs) or non-Coast Guard resources such as a manufacturer’s overhaul facility.

3. Does maintenance technical information exist?
Answer: Yes.

Explanation: The original equipment manufacturer provided the MTU 20 V 1163 TB93 Maintenance Schedule (MTU, 2013), a detailed technical publication, and equipment parts lists as deliverables upon acquisition. The technical information is available in the English language and in an easily accessible digital format. Unfortunately, detailed task data regarding task duration and technician quantities is not provided and was determined by Coast Guard staff during the creation of Coast Guard MPCs. The MPCs are currently being validated by Coast Guard Training Center Yorktown for implementation at the next MPC revision event.

4. Is the component available through the organization's supply chain?

Answer: Yes.

Explanation: The MTU 20 V 1163 Diesel Engine is currently available for purchase from the original equipment manufacturer through a formal acquisition contract. Individual parts, components, assemblies, and subassemblies of the engine are available for purchase through the Coast Guard procurement system. The Surface Forces Logistics Center determines which parts are to be stocked for rapid access at Coast Guard Inventory Control Points.

5. Are special tools required and available?

Answer: Yes.

Explanation: The special tools required to complete all QL3 maintenance tasks are available at designated NSC MATs. The costs associated with these tools are considered
sunk costs as they were provided as an element of the original equipment acquisition and unit provisioning effort upon commissioning of the MAT. The special tools are available for purchase through the Coast Guard procurement system. The special tools are proprietary to the original equipment manufacturer and are considered a neutral cost between resources due to the common price and source.

6. Are depot maintenance facilities required and available?

Answer: Yes.

Explanation: Each cutter home port has a MAT facility. NSC MAT facilities are considered a sunk cost due to their existence as a MAT facility for other cutter classes prior to the establishment of NSC home ports (no new construction or alteration). This determination aligns with government facility utilization practices. Should the MAT be moved or decommissioned, the facility would be repurposed for other government utilization.

7. Does the component present environmental impacts?

Answer: Yes.

Explanation: Diesel engines present environmental impacts. Fuels and lubricants are readily available in home ports (supply impacts). Handling and disposal of these materials are in accordance with state, local, and federal regulations (hazardous material impacts). Each home port is located on a Coast Guard Base with hazardous material control policies and resources available for both cutter and MAT use. Cutters have fuel and lubricating oil transfer and storage systems to facilitate liquid transfers. Crews are properly trained to complete flammable liquid transfers. MAT facilities are outfitted with
approved parts cleaners for which routine maintenance and support is established through the Base. Liquid oily waste storage, transfer, and disposal are coordinated by cutter crews, and oily rag disposal is the responsibility of both cutter and MAT facilities.

8.a. Do designated technicians exist in the organization?

Answer: Yes.

Explanation: D-level technicians are assigned to each cutter’s designated MAT. The Coast Guard’s model NSC MAT is MAT Alameda. The MAT Alameda Personnel Allowance List (PAL) is shown in Table 4-5. MAT Alameda has 34 military technicians (rank E4-E8) and 2 Chief Warrant Officer (CWO) supervisors. NSC MATs also exist in Charleston, SC, and Honolulu, HI home ports.

In a Coast Guard memorandum dated 30 March 2017, SFLC’s Long Range Enforcer Product Line (SFLC-LREPL) and Industrial Operations Division (IOD) determined that solely relying on non-Coast Guard technicians to provide depot maintenance support is unsustainable. The memorandum documents IOD’s commitment to an “Organic First” philosophy to prioritize the employment of Coast Guard technicians to reduce life cycle costs. The memorandum proposes the establishment of MAT Alameda as an MTU Center of Excellence and of two specialized teams to provide flexible travel to NSC homeports in Honolulu and Charleston and ports of call for the execution of corrective maintenance. The composition of the proposed team can be seen alongside the current MAT Alameda PAL in Table 4-5.
Table 4-5: Maintenance Augmentation Team Alameda Personnel Allowance List

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<th># of Personnel</th>
<th>Position Equivalency</th>
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<td>2</td>
<td>1-Supervisor, 1-Duty</td>
<td>1 – Supervisor</td>
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<td>E8 – MKCS</td>
<td>1</td>
<td>Senior Technician</td>
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<tr>
<td>E7 – MKC</td>
<td>1</td>
<td>Senior Technician</td>
<td>2* – Mech Team Lead</td>
</tr>
<tr>
<td>E6 – MK1</td>
<td>5</td>
<td>Basic Technician</td>
<td>4 – Mech Team Mbr</td>
</tr>
<tr>
<td>E5 – MK2</td>
<td>7</td>
<td>Basic Technician</td>
<td>4 – Mech Team Mbr</td>
</tr>
<tr>
<td>E4 – MK3</td>
<td>8</td>
<td>Journeyman Technician</td>
<td>4 – Mech Team Mbr</td>
</tr>
<tr>
<td>E7 – EMC</td>
<td>1</td>
<td>Advanced Technician</td>
<td>2* – Elec Team Lead</td>
</tr>
<tr>
<td>E6 – EM1</td>
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<tr>
<td>E5 – EM2</td>
<td>7</td>
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</tr>
<tr>
<td>E4 – EM3</td>
<td>2</td>
<td>Journeyman Technician</td>
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</table>

8.b. Do qualified technicians exist in the industry (OEM or equivalent)?

Answer: Yes.

Explanation: The Coast Guard maintains a service contract with the original equipment manufacturer to provide depot maintenance support for systems in sustainment. The sustainment support contract is maintained by the Coast Guard’s Surface Forces Logistics Center and draws support from original equipment manufacturer resources dedicated to the Alameda, CA area. Technical warranty support is also provided for cutters operating within acquisition life cycle phase or transitioning to sustainment. However, there is a limited pool of OEM technicians available nationwide thus increasing a potential dependence on commercial technicians that have far less experience completing MTU maintenance.

8.c. Is training to develop technician competency available?
Answer: Yes.

Explanation: The Coast Guard established a need for MTU 20 V 1163 training in fiscal year 2006 as a result of a Deepwater acquisition program front-end analysis. The Coast Guard performed several more front-end analyses between 2007 and 2016 to determine resource and curriculum design requirements for the Coast Guard to produce resident training courses at Coast Guard Training Center Yorktown. Coast Guard training staff were sent to MTU company schools to complete all courses and bring the knowledge and methods to the Coast Guard Training Center. The MTU 1163-series courses reside in the Coast Guard Training Center’s Engineering Systems School, a facility outfitted with a functional propulsion diesel engine, reduction gear, local and remote operating stations, classrooms, and training materials (tools, print and digital content, and test equipment).

The NSC Basic course is two weeks in duration and targets cutter crews and aspiring advanced-level technicians. The course curriculum is focused on basic operation and maintenance of the 1163-series engine. The NSC Basic course serves as a prerequisite for the NSC advanced course. The course is currently available.

The NSC advanced course is in final stages of development, is three weeks in duration, and targets MAT D-level maintainers and two senior technicians of each cutter crew. The course curriculum is focused on advanced system knowledge and the completion of all QL3 maintenance tasks. It provides technicians with the knowledge and skills required to maintain the NSC propulsion diesel engine. The courses are aligned with the original equipment manufacturer’s company-provided courses and will be available in summer of 2018.
In 2017, the Coast Guard awarded a five-year contract to MTU for company-instructed basic and advanced training. These courses use the Coast Guard Training Center’s resources and an MTU-provided instructor. The contract was established to provide schedule flexibility and advanced technician courses while the Coast Guard completes development of an advanced technician course. The average cost of a two-week MTU-hosted course is $44,000 compared to a $16,000 Coast Guard-hosted course at the same facility. Additionally, course completion surveys have disclosed numerous issues related to MTU instructor performance, increasing the need for a resident Coast Guard MTU advanced technician course.

4.2.3 National Security Cutter Economic Analysis

Table 4-6 displays labor rate calculations for NSC preventive depot maintenance procedures. The table lists the MPC title, the cost for each level technician (military and non-military) and sum cost of each task by the resource. In brief, the Coast Guard is the lowest cost resource at $21,997.09 while non-Coast Guard technicians are estimated at $57,904.23, and a blend of 2 non-Coast Guard supervisors and 5 Coast Guard technicians estimated at $32,538.38.

Table 4-6: NSC Preventive Depot Maintenance Labor Rate Calculations

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Table 4-7 provides a view of the outputs of the economic analysis form. Total estimated costs benefit the contractor at first glance. However, lower labor rates and a rapid return on training development investment shift the benefit to the Coast Guard.

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<th>Repair by Non-CG $</th>
<th>Repair by Blend $</th>
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<td>Total labor rate per resource</td>
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<td>Sunk cost (acquisition)</td>
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<td>Neutral cost (CG procured in all situations)</td>
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<td>Acquire facilities &amp; tools, SFLC fund validation, CG-4 fund FEA</td>
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<td>Technician Training</td>
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</tr>
<tr>
<td>Technical data cost</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>Sunk cost (acquisition)</td>
</tr>
<tr>
<td>Disposal cost</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>No disposal</td>
</tr>
<tr>
<td>Total estimated cost</td>
<td>$1,631,997.09</td>
<td>$1,590,904.23</td>
<td>$1,646,038.38</td>
<td></td>
</tr>
</tbody>
</table>

Labor rates for a one-time completion of all tasks by a Coast Guard team are $21,997.09, whereas a non-Coast Guard team costs $57,904.23 and a blended team costs $32,538.38. On a purely quantitative basis, this provides the Coast Guard team with far more labor hour flexibility should a team encounter task interferences (2.6:1 ratio). The use of a blend provides a healthy cost compromise between Coast Guard and non-Coast Guard technicians should the organization wish to buy down risk by introducing an advanced original equipment manufacturer technician to supervise the team, develop reports, and provide limited warranty coverage.

The costs associated with training development for the Coast Guard ($98,000) are a worthy investment when one considers the cost of each provider. Technical training costs
provide the minimum training requirements for a Coast Guard team, a non-Coast Guard
team, and a blended team. Each of these teams will attend a course with an eight-student
capacity hosted at the Coast Guard Training Center. If the course is delivered by Coast
Guard instructors, a seat costs $2000. If the course is delivered by an OEM instructor
(contractor), a seat costs $5500. One manufacturer-instructed course using the Training
Center’s resources costs an estimated $44,000 for eight students. One Coast Guard-
instructed course at the Training Center costs an estimated $16,000 for eight students.
Sending technicians to a Coast Guard-provided course versus a contractor-provided
course saves $28,000 per course. Therefore, the Coast Guard realizes a return on
investment after completing 3 Coast Guard-instructed courses.

\[
16,000 \times 3 = 48,000 \quad (4.3)
\]

The results of Table 4-7 are visually depicted in Figure 4-2, NSC Preventive
Maintenance Resource Labor Rate Column Chart.

![Figure 4-2: NSC Preventive Maintenance Labor Rate Column Chart](image)
Figure 4-2 visually depicts the variations in resource costs per task. The column chart shows that non-Coast Guard technician labor rates far exceed Coast Guard or blended labor rates for Jacket Water 9156 Treatment, 36 Inch Expansion Joint, Fuel Injector Pumps, Engine Boroscope, and Engine Signature Analysis tasks. These tasks present the greatest opportunity to maximize resource flexibility through blended teams comprised of two advanced non-Coast Guard technicians and five Basic Coast Guard technicians. A review of the remaining tasks further enforces the proposal that a blended maintenance team presents the most beneficial approach as costs are close to Coast Guard labor rates and risks are reduced by having an advanced non-Coast Guard technician supervise the team, apply proprietary knowledge of systems, provide multiple resources for immediate employment, and potentially carry limited warranty protection.

4.2.4 National Security Cutter Decision Analysis

The previous analyses reveal a need for a 10-year transition from complete dependency on original equipment manufacturers to a blended resource approach through the development of Coast Guard depot maintenance technicians. Figure 4-3 displays 3 phases of implementation of all logistics program initiatives occurring within the 10 year period. The following timeline is recommended:
The proposed 10-year plan will provide the Coast Guard the time to transition from complete dependency on non-Coast Guard support and establish a more sustainable maintenance program. Each phase is designed to allow processes and products to develop in lockstep as resources become available and deliverables are produced to feed the next phase. The first period, years 0-5, produce the foundational elements for maintenance program execution. The second period, years 5-10 allow those elements to refine and mature to a desired state while performance data is collected and analyzed. Finally, the third period, which carries the asset into complete sustainment, provides complete service to the fleet and a renewed LORA.

In years 0-5 (solely acquisitions phase), logisticians establish foundational support from the original equipment manufacturer. This period allows the organization to obtain the technical information, special tools, service agreements, and supply chain elements
needed to build an internal maintenance program. The period also provides for the
development and staffing of maintenance teams, a training facility, and the validation of
preliminary maintenance procedure cards (MPCs).

The second phase (years 5-10) builds on the successes of the previous period. The
organization can renew service agreements with original equipment manufacturers based
on new program realities. These contracts should consider operating cutter home port
locations, the rate of equipment casualties driving corrective maintenance, and the status
of spare parts and tool availability. The contract renewal provides an opportunity to
address shortfalls should the aforementioned logistics are insufficient.

With training resources in place, front-end analyses (FEA) can identify training
requirements and initiate course development. It is important to note that the FEA and
course development process can last up to three years depending upon the availability of
developers and course materials and the willingness of programs to fund these efforts.
Also, it is imperative that all MPCs are written and validated before moving into training
analyses as these tasks provide the detailed technical requirements for course objectives.
The absence of validated MPCs will delay course development and require MPCs to be
validated at the training center during curriculum design. This can unnecessarily delay
course creation, drastically increase budget requirements, and fall short of meeting the
goal of validating MPC at the site of maintenance execution (e.g., the cutter engine
room). NSC MPCs are currently not validated and will negatively impact course
development.

Phase 3 moves the program into a full sustainment status. After two iterations of
contracted OEM support (5 years each), maintenance planners and senior engineering
strategists can initiate a new LORA to update analyses and establish new baselines. The phase 3 LORA will be based on real maintenance completion data including failure rates and modes, the effectiveness and availability of maintenance resources, and at least two iterations of a Maintenance Effectiveness Review. This LORA will inform the maintenance program for another 5-10 years.

The end-state of the maintenance program in the sustainment phase provides proficient Coast Guard technicians, a flexible non-Coast Guard technician support contract, and the ability to integrate the two resources through a blended maintenance model. The result is a lean system with low contracted labor demands, the increased flexibility provided by multiple resources, and reduced technical risk.

4.2.5 National Security Cutter Sensitivity Analysis

Labor Rate Breakeven Ratios are depicted in Table 4-8, NSC Sensitivity Analysis Labor Rate Breakeven Ratios. The ratios show the least total cost difference between Coast Guard and blended maintenance teams whereas the greatest cost difference exists between non-Coast Guard and Coast Guard teams. This data can be used on a task-by-task basis to analyze the weight of resource cost impacts at resource selection.

The breakeven ratios align with this praxis’s observations in Figure 4-2, NSC Preventive Maintenance Resource Labor Rate Column Chart. The ratios indicate the highest and lowest financial risks between two resources for all tasks. High ratios are show the greatest cost disparity between two assessed resources. These tasks are a good starting point for resource selection as they pose the highest financial risk. However, it is highly discouraged to make resource selections based solely on estimated costs.
Noneconomic factors must be weighed prior to understanding the risk associated with each selection.

Low ratios indicate little difference between estimated labor costs and provide leverage for strategic resource decisions based on total program risks. In most cases, the selection for low ratio tasks will default to the organization’s resources in order to realize the highest return on internal resource investments and free external resources for their dedicated tasks. This method may also provide schedulers with healthier resource environments as buffer periods will be less constrained for complex tasks and availability improved for unplanned maintenance events (corrective).

Table 4-8: NSC Sensitivity Analysis Labor Rate Ratios

<table>
<thead>
<tr>
<th>Title</th>
<th>Labor $ per hour</th>
<th>CG Total Labor $</th>
<th>Non-CG Total Labor $</th>
<th>Blend Total Labor $</th>
<th>Non-CG Total Labor/CG Total Labor</th>
<th>Sensitivity Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>JACKET WATER 9156 TREATMENT TO GLYSACORR (G-3)</td>
<td>$299.18</td>
<td>$2,393.41</td>
<td>$6,728.00</td>
<td>$3,944.03</td>
<td>2.811</td>
<td>1.648  1.705</td>
</tr>
<tr>
<td>CYLINDER HEAD</td>
<td>$385.35</td>
<td>$924.84</td>
<td>$1,211.00</td>
<td>$2,690.40</td>
<td>$493.00</td>
<td>1.183  2.724</td>
</tr>
<tr>
<td>32 INCH EXPANSION JOINT</td>
<td>$213.00</td>
<td>$1,136.02</td>
<td>$561.00</td>
<td>$2,992.00</td>
<td>$213.00</td>
<td>1.316  2.694</td>
</tr>
<tr>
<td>LIQUID LEVEL INDICATOR</td>
<td>$77.00</td>
<td>$568.01</td>
<td>$187.00</td>
<td>$1,496.00</td>
<td>$77.00</td>
<td>1.563  2.634</td>
</tr>
<tr>
<td>JACKET WATER PUMP</td>
<td>$213.00</td>
<td>$1,136.02</td>
<td>$561.00</td>
<td>$2,992.00</td>
<td>$493.00</td>
<td>2.634  2.634</td>
</tr>
<tr>
<td>LUBE OIL THERMOSTAT</td>
<td>$142.00</td>
<td>$142.00</td>
<td>$374.00</td>
<td>$1,768.00</td>
<td>$142.00</td>
<td>1.259  1.634</td>
</tr>
<tr>
<td>36 INCH EXPANSION JOINT</td>
<td>$284.01</td>
<td>$1,136.02</td>
<td>$748.00</td>
<td>$2,992.00</td>
<td>$284.01</td>
<td>1.136  2.634</td>
</tr>
<tr>
<td>HIGH PRESSURE (HP) INTERCOOLER</td>
<td>$331.40</td>
<td>$2,350.51</td>
<td>$791.00</td>
<td>$5,932.50</td>
<td>$493.00</td>
<td>1.090  2.634</td>
</tr>
<tr>
<td>FUEL INJECTOR PUMPS</td>
<td>$142.00</td>
<td>$2,840.06</td>
<td>$748.00</td>
<td>$2,992.00</td>
<td>$142.00</td>
<td>1.136  2.634</td>
</tr>
<tr>
<td>ENGINE BORESCOPE</td>
<td>$242.40</td>
<td>$3,879.40</td>
<td>$604.00</td>
<td>$5,664.00</td>
<td>$422.00</td>
<td>1.479  1.431</td>
</tr>
<tr>
<td>LUBE-OIL PUMP</td>
<td>$142.00</td>
<td>$426.01</td>
<td>$374.00</td>
<td>$1,212.00</td>
<td>$142.00</td>
<td>1.426  1.363</td>
</tr>
<tr>
<td>HIGH PRESSURE CHARGE AIR COOLER</td>
<td>$142.00</td>
<td>$568.01</td>
<td>$374.00</td>
<td>$1,136.02</td>
<td>$142.00</td>
<td>1.624  1.634</td>
</tr>
<tr>
<td>LOW PRESSURE CHARGE AIR COOLER</td>
<td>$142.00</td>
<td>$568.01</td>
<td>$374.00</td>
<td>$1,136.02</td>
<td>$142.00</td>
<td>1.624  1.634</td>
</tr>
<tr>
<td>EXHAUST TURBOCHARGER</td>
<td>$284.01</td>
<td>$2,156.05</td>
<td>$748.00</td>
<td>$6,732.00</td>
<td>$564.01</td>
<td>1.986  1.326</td>
</tr>
<tr>
<td>ENGINE SIGNATURE ANALYSIS</td>
<td>$257.57</td>
<td>$1,379.71</td>
<td>$697.00</td>
<td>$3,717.33</td>
<td>$351.00</td>
<td>1.573  1.986</td>
</tr>
</tbody>
</table>

A one-way sensitivity analysis calculates the estimated cost of labor should planned maintenance tasks take less or more time to complete than the maintenance procedure card dictates. One-way sensitivity analysis for National Security Cutter labor resources is shown in Tables 4-9, 4-10, and 4-11. Each Table shows the calculation of various task duration multiples for the total labor cost of Coast Guard (Table 4-9), Non-Coast Guard (Table 4-10), and Blended Team (Table 4-11) resources. Each table provides analysts...
Table 4- 10: One-Way Sensitivity Analysis of NSC Coast Guard Labor Task Durations

<table>
<thead>
<tr>
<th>Title</th>
<th>Task Duration Multiple</th>
</tr>
</thead>
<tbody>
<tr>
<td>JACKET WATER RISSE TREATMENT TO G8</td>
<td>1.00</td>
</tr>
<tr>
<td>CYLINDER HEAD 1</td>
<td>1.04</td>
</tr>
<tr>
<td>CYLINDER HEAD 2</td>
<td>1.08</td>
</tr>
<tr>
<td>CYLINDER HEAD 3</td>
<td>1.12</td>
</tr>
<tr>
<td>CYLINDER HEAD 4</td>
<td>1.16</td>
</tr>
<tr>
<td>CYLINDER HEAD 5</td>
<td>1.20</td>
</tr>
<tr>
<td>CYLINDER HEAD 6</td>
<td>1.24</td>
</tr>
<tr>
<td>CYLINDER HEAD 7</td>
<td>1.28</td>
</tr>
<tr>
<td>CYLINDER HEAD 8</td>
<td>1.32</td>
</tr>
<tr>
<td>CYLINDER HEAD 9</td>
<td>1.36</td>
</tr>
<tr>
<td>CYLINDER HEAD 10</td>
<td>1.40</td>
</tr>
</tbody>
</table>

Table 4- 11: One-Way Sensitivity Analysis of NSC Blended Labor Task Durations

<table>
<thead>
<tr>
<th>Title</th>
<th>Task Duration Multiple</th>
</tr>
</thead>
<tbody>
<tr>
<td>JACKET WATER RISSE TREATMENT TO G8</td>
<td>1.00</td>
</tr>
<tr>
<td>CYLINDER HEAD 1</td>
<td>1.04</td>
</tr>
<tr>
<td>CYLINDER HEAD 2</td>
<td>1.08</td>
</tr>
<tr>
<td>CYLINDER HEAD 3</td>
<td>1.12</td>
</tr>
<tr>
<td>CYLINDER HEAD 4</td>
<td>1.16</td>
</tr>
<tr>
<td>CYLINDER HEAD 5</td>
<td>1.20</td>
</tr>
<tr>
<td>CYLINDER HEAD 6</td>
<td>1.24</td>
</tr>
<tr>
<td>CYLINDER HEAD 7</td>
<td>1.28</td>
</tr>
<tr>
<td>CYLINDER HEAD 8</td>
<td>1.32</td>
</tr>
<tr>
<td>CYLINDER HEAD 9</td>
<td>1.36</td>
</tr>
<tr>
<td>CYLINDER HEAD 10</td>
<td>1.40</td>
</tr>
</tbody>
</table>

with an estimated labor cost for each task experiencing various task duration changes.
The Tables serve as inputs to Figure 4-4, National Security Cutter One-Way Sensitivity Graph, which depicts the estimated total labor costs for each resource at various levels of program maintenance duration. Figure 4-4 reports input values (duration multiples) on the x-axis and the calculated consequence (program labor cost) on the y-axis (Clemen & Reilly, 2014). Figure 4-4 shows the cost of each resource increasing in a linear fashion in response to each duration increase. As maintenance durations increase, the estimated cost disparity between each resource becomes more pronounced. This shows the growing levels of financial risk between resources as durations increase. The sensitivity graph shows a max cost estimate of $65,991.26 for Coast Guard technicians, $173,712.70 for Non-Coast Guard technicians, and $97,615.14 for a Blended Team. The light blue indicates a breakeven point ($65,991.26) for Coast Guard technicians against the other two resources and the dotted green line indicates a breakeven point ($97,615.14) for the Blended Team against Non-Coast Guard technicians. Figure 4-4 implies a lower financial risk (valued at $107,721.44) of choosing Coast Guard technicians over Non-Coast Guard technicians (highest cost) under conditions of task duration uncertainty. The financial risk is calculated by subtracting the lower cost resource from the highest cost resource.

\[
\text{resource (A) estimated total labor cost - resource (B) total estimated labor cost = financial risk value}
\] (4.4)
The Famous Class is a Coast Guard Medium Endurance Cutter (MEC) designed in the 1970s for maritime law enforcement and national defense missions. The MEC is 270 feet in length with a beam (width) of 38 feet and a draft of 14.5 feet and is regularly operates away from home port for an average of 180 days a year. There are 13 hulls in service with homeports in Norfolk, VA, Boston, MA, Portsmouth, NH, and Key West, FL.

Maintenance Augmentation Teams (MAT) located in the home port’s vicinity are dedicated to the execution of the MEC’s depot maintenance (D-level). The MAT is staffed to support depot maintenance on the MEC’s various systems including the propulsion diesel engines. Unlike the NSC scenario, MAT technicians have been provided the training and experience required to perform their prescribed maintenance and sustainment programs have been in place for decades. This situation has significantly

Figure 4- 4: NSC One-Way Sensitivity Graph

4.3 270-Foot Medium Endurance Cutter Level of Repair Analysis

The Famous Class is a Coast Guard Medium Endurance Cutter (MEC) designed in the 1970s for maritime law enforcement and national defense missions. The MEC is 270 feet in length with a beam (width) of 38 feet and a draft of 14.5 feet and is regularly operates away from home port for an average of 180 days a year. There are 13 hulls in service with homeports in Norfolk, VA, Boston, MA, Portsmouth, NH, and Key West, FL.

Maintenance Augmentation Teams (MAT) located in the home port’s vicinity are dedicated to the execution of the MEC’s depot maintenance (D-level). The MAT is staffed to support depot maintenance on the MEC’s various systems including the propulsion diesel engines. Unlike the NSC scenario, MAT technicians have been provided the training and experience required to perform their prescribed maintenance and sustainment programs have been in place for decades. This situation has significantly
decreased dependency on industry technicians for the completion of most preventative and corrective D-level maintenance. Currently, only the most advanced and high-risk tasks, such as diesel engine top end or complete overhauls, draw non-Coast Guard technicians. A LORA will determine whether the Coast Guard should implement changes to its current maintenance model as the vessel approaches the end of its life cycle, equipment obsolescence occurs, and maintenance demands increase.

**4.3.1 Medium Endurance Cutter Assumptions**

Independent Variables:

- Maintenance procedure cards (MPCs)
- National Industrial Enterprise resources (Coast Guard technicians)
- Contract maintenance resources (non-Coast Guard technicians)
- Training resources (training availability, course types)

Dependent variables:

- Maintenance cost per man-hour (MCPMH) for Coast Guard technicians
- Maintenance cost per man-hour (MCPMH) for contracted technicians
- Life cycle sustainment cost projections
- Training cost projections
- Coast Guard technician proficiency (measured by the capability to perform specific maintenance tasks). Rating Performance Qualifications establish baseline technical proficiency requirements for Coast Guard technicians and are used to determine the appropriate level of a technician for task execution.

**4.3.2 Medium Endurance Cutter Noneconomic Analysis**

1. Does component failure inhibit equipment operation?
Answer: Yes.

Explanation: A loss of propulsion diesel engine component function requires the engine to be secured and repaired. The engine will be unavailable until O- or D-level corrective maintenance is performed to restore the engine to operational status. While the engine is secured, the cutter is limited to using the other propulsion diesel engine for maneuvering. This is most impactful when mooring or unmooring the vessel in a port or while operating at sea in close quarters to other vessels during the execution of primary missions. This is least impactful while the cutter is moored in home port in a depot maintenance availability.

2.a. Does equipment manufacturer or CG recommend PM task(s)?

Answer: Yes.

Explanation: Both the Coast Guard and manufacturer prescribe preventive maintenance tasks. The Coast Guard built the engine’s MPCs from the manufacturer’s maintenance schedule. The MPCs are validated and a fulltime diesel engine maintenance program manager oversees diesel engine inspection and top end overhaul logistics (schedule, provision, analysis, and performance). MPCs were extracted from the Coast Guard Logistics Information Management System (CG LIMS) database.

2.b. Does the complexity of the task(s) exceed D-level maintainer competency?

Answer: Yes.

Explanation: The current depot maintenance tasks prescribed by Coast Guard MPCs were designed based on three decades of Famous Class maintenance performance and
criteria of the bi-level maintenance philosophy. The cutter crew is staffed to complete O-level preventive maintenance which is operational checks and maintenance that does not require depot maintenance resources. Cutter crews may be tasked with completing some depot maintenance which is solely corrective maintenance requiring the replacement of a component while away from home port. The Coast Guard assigns D-level maintenance to Coast Guard Maintenance Augmentation Teams (MATs) and some advanced depot maintenance tasks (diesel engine inspections, top end overhauls, and catastrophic corrective equipment casualties) to a non-Coast Guard master diesel mechanic under a current support contract. Therefore, all prescribed depot MPCs are the focus of this analysis and all other maintenance is automatically prescribed to cutter crews and the non-Coast Guard technician.

2.c. What is the estimated task duration in total hours?

Answer: 85.43

Explanation: The estimated task duration is shown in Table 4-9, MEC Preventive Depot Maintenance Procedure Task Data, as the sum of Team Labor Hours. The duration data prescribed for each applicable Coast Guard MPC is reported as Hours Per Component and Number of Technicians. The numbers are extracted from each MPC to determine Team Labor Hours in the following equation:

\[
\text{Hours Per Component} / \text{Number of Technicians} = \text{Team Labor Hours}
\]

Team Labor Hours indicate the total estimated time period a team of technicians will be onsite to perform a task. Once, all Team Labor Hours are identified, they are summed
to estimate the Team Labor Hours required to complete all prescribed maintenance tasks one time.

Table 4-12: MEC Preventive Depot Maintenance Task Data

<table>
<thead>
<tr>
<th>Type</th>
<th>Asset Class</th>
<th>Title</th>
<th>MPC Number</th>
<th>Revision Date</th>
<th>Hours per component</th>
<th>Number of Techs</th>
<th>Team Labor Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPC 270</td>
<td>Diesel</td>
<td>TURBO CHARGER REPLACE</td>
<td>M-C-8499</td>
<td>3/10/2016</td>
<td>12</td>
<td>3</td>
<td>4.10</td>
</tr>
<tr>
<td>MPC 270</td>
<td>Diesel</td>
<td>LUBE OIL PUMP REPLACE</td>
<td>M-C-1382</td>
<td>2/28/2017</td>
<td>6</td>
<td>4</td>
<td>1.50</td>
</tr>
<tr>
<td>MPC 270</td>
<td>Diesel</td>
<td>AFTERCOOLER INSPECT AND CLEAN</td>
<td>M-C-1371</td>
<td>4/10/2016</td>
<td>48</td>
<td>5</td>
<td>9.60</td>
</tr>
<tr>
<td>MPC 270</td>
<td>Diesel</td>
<td>FULL POWER GROUNDS INSPECTION</td>
<td>M-C-8461</td>
<td>8/10/2016</td>
<td>16</td>
<td>6</td>
<td>7.03</td>
</tr>
<tr>
<td>MPC 270</td>
<td>Diesel</td>
<td>BIENNIAL MAIN DIESEL ENGINE INSPECT</td>
<td>M-C-8494</td>
<td>3/15/2017</td>
<td>44</td>
<td>1</td>
<td>44.00</td>
</tr>
<tr>
<td>MPC 270</td>
<td>Diesel</td>
<td>JACKET WATER COOLER INSPECTION</td>
<td>M-C-1405</td>
<td>6/10/2016</td>
<td>4</td>
<td>2</td>
<td>2.00</td>
</tr>
<tr>
<td>MPC 270</td>
<td>Diesel</td>
<td>LUBE OIL COOLER INSPECT AND CLEAN</td>
<td>M-C-1403</td>
<td>6/10/2016</td>
<td>4</td>
<td>2</td>
<td>2.00</td>
</tr>
<tr>
<td>MPC 270</td>
<td>Diesel</td>
<td>REMOVE MDX AND I/O RELIEF VALVES FOR TESTING</td>
<td>M-C-1387</td>
<td>4/30/2004</td>
<td>16</td>
<td>2</td>
<td>8.00</td>
</tr>
<tr>
<td>MPC 270</td>
<td>Diesel</td>
<td>CYLINDER HEAD REPLACE* (Divided to single cylinder)</td>
<td>M-C-13216</td>
<td>7/15/2017</td>
<td>116.6666667</td>
<td>10</td>
<td>11.67</td>
</tr>
</tbody>
</table>

Sum: 85.43

2.d. What level technicians are required? (circle applicable)

Answer: Basic and Advanced Technicians

Explanation: Basic MEC MAT technicians (rank E4-E6) are provided sufficient on-the-job training through participation in maintenance team tasks. These teams are led by advanced technicians, some of which attend ALCO 251 training provided by the U.S. Navy. Advanced technicians (rank E7-E8) require no further equipment-specific training but require more advanced trade skills and experience. Thus, the requirement for the higher military rank or equivalent industry qualification delineates the difference between advanced and basic level technicians.

2.e. How many technicians are required per qualification level?

Answer: 8 Basic and 2 Advanced Trained Technicians

Explanation: The number of technicians required per qualification level is based on the maximum number of each level technician required for a single task. Table 4-12, MEC Preventive Depot Maintenance Task Data, displays the number of technicians
required for each maintenance task by the planned maintenance program. Table 4-13, MEC Depot Maintenance Task Data for 1 Year MAT Performance, displays the number of technicians assigned to each maintenance task completed by MAT Portsmouth in 2017. The analysis accounted for each task occurring independently. The stated requirement of four basic and two advanced level technicians is predicated on tasks occurring in series, not parallel. The LORA does not present an estimation of the optimal number of MAT technicians required to complete tasks on a routine basis. That determination occurs when the Coast Guard conducts a Manpower Requirements Analysis.

**Table 4-13: MEC Depot Maintenance Task Data for 1 Year MAT Performance**

<table>
<thead>
<tr>
<th>Depot Maintenance Execution (Historical 270', MAT)</th>
<th>Task Data</th>
<th>Coast Guard Labor Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Asset Class</td>
<td>Title</td>
</tr>
<tr>
<td>COR 270 PUMP TEST FUEL INJECTORS</td>
<td>M-5-12048</td>
<td>32</td>
</tr>
<tr>
<td>COR 270 NR2 REPLACE IR CYLINDER HEAD</td>
<td>93</td>
<td>6</td>
</tr>
<tr>
<td>MPC 270 BIOMIAL DIESEL ENGINE INSPECTION</td>
<td>M-C-8494</td>
<td>104</td>
</tr>
<tr>
<td>COR 270 CROSS CONNECT BUTTERFLY VALVE NR1 MDE</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>COR 270 CROSS CONNECT BUTTERFLY VALVE NR2 MDE</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>COR 270 FUEL PUMP REPLACEMENT</td>
<td>74.5</td>
<td>5</td>
</tr>
<tr>
<td>COR 270 NR1 MDE JACKET WATER COOLER</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>COR 270 REPLACE NR1 MDE AFTERCOOLER</td>
<td>98</td>
<td>11</td>
</tr>
<tr>
<td>COR 270 NR1 MDE CAMSHAFT REPLACEMENT (INBOARD)</td>
<td>124</td>
<td>5</td>
</tr>
<tr>
<td>MPC 270 NR1 MDE DIESEL ENGINE INSPECTION</td>
<td>M-C-8494</td>
<td>192</td>
</tr>
<tr>
<td>MPC 270 NR2 MDE DIESEL ENGINE INSPECTION</td>
<td>M-C-8494</td>
<td>112</td>
</tr>
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<td>MPC 270 NR1 MDE EXHAUST INSPECTION AND CLEAN</td>
<td>M-Q-476</td>
<td>2</td>
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<tr>
<td>COR 270 NR2 MDE JACKET WATER COOLER REPLACEMENT</td>
<td>124</td>
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<td>MPC 270 AIR START MOTOR NR1</td>
<td>M-A-8400</td>
<td>3</td>
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<td>COR 270 CAMSHAFT NR1 MDE</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>MPC 270 CLEAN NR1 MDE JACKET WATER COOLER</td>
<td>?</td>
<td>95</td>
</tr>
<tr>
<td>MPC 270 CLEAN NR2 MDE JACKET WATER COOLER</td>
<td>?</td>
<td>52</td>
</tr>
<tr>
<td>COR 270 REPLACE MDE JACKET WATER &amp; RAW WATER PUMPS</td>
<td>76 7 6 10.86</td>
<td>0 0 1 2 4 0</td>
</tr>
<tr>
<td>MPC 270 MDE EXHAUST INSPECTION AND CLEAN</td>
<td>M-Q-484</td>
<td>11</td>
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<tr>
<td>COR 270 NR1 MDE OIL COOLER CASUALITY</td>
<td>174</td>
<td>5</td>
</tr>
<tr>
<td>COR 270 NR2 MDE RAW WATER PUMP REVIVAL</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>MPC 270 DEI MDE FULL POWER GROOM</td>
<td>M-A-8495</td>
<td>8.5</td>
</tr>
<tr>
<td>MPE 270 MDE JACKET WATER COOLER INSPECTION/CLEANING</td>
<td>M-C-445</td>
<td>48</td>
</tr>
<tr>
<td>COR 270 DEI MDE FULL POWER GROOM</td>
<td>M-C-445</td>
<td>43</td>
</tr>
</tbody>
</table>

| Sum   | 115.33 |

2.f. Do any existing support contracts cover the task?

**Answer:** Yes.

**Explanation:** The Coast Guard maintains a service contract with a non-Coast Guard master diesel mechanic to provide depot maintenance support for advanced engine
maintenance. Warranty support does not exist for the MEC propulsion diesel engine. The service contract has significantly improved the quality of select advanced tasks and their associated reports.

2.g. How does the task align with the organization's (Coast Guard’s) maintenance philosophy?

Answer: The MEC maintenance philosophy complies with the Coast Guard’s Bi-Level Maintenance Model which divides all maintenance into either Organizational (O) or Depot (D) levels. As stated in the NSC ILSP, “O-level maintenance, is maintenance that is within the expertise of the crew and which the crew has the necessary tools and the authority to perform. D-level maintenance is material maintenance or repair requiring the overhaul, upgrading, or rebuilding of an asset or its components, assemblies, or subassemblies. D-level maintenance requires the highest level of maintenance capability, particularly that which is beyond the workload capacity of the crew” (USCG, 2013).

Through decades of sustainment phase asset management, the Coast Guard developed a comprehensive maintenance program to support engine performance. The repair or discard decision for MEC propulsion engine parts defaults to “repair” since all parts are required for proper engine function. This LORA is thus focused on determining the level of repair at which the maintenance task will be completed. D-level maintenance must be completed by advanced technicians found at Coast Guard Maintenance Augmentation Teams (MATs) or non-Coast Guard resources such as a manufacturer’s overhaul facility. The assignment of select MEC depot maintenance tasks to non-Coast Guard technicians is determined based on task complexity and duration. Diesel engine inspections and top end overhauls have been identified as the planned depot maintenance tasks that require a
non-Coast Guard technician supervisor. The non-Coast Guard technician supervises a team of Coast Guard Basic technicians who serve as a labor force. This team construct provides Coast Guard technicians with invaluable experience and on-the-job training and ensures consistent task quality and reporting for all such tasks across the MEC fleet. The benefits of this maintenance plan can be used as positive lessons learned for the development of maintenance plans for new assets such as the NSC.

3. *Does maintenance technical information exist?*

   **Answer:** Yes.

   **Explanation:** The original equipment manufacturer provided a detailed technical publication, service digests, and equipment parts list over the life cycle of the engine. The technical information is available in the English language, of sufficient detail and scope, and in an easily accessible digital format. Detailed task data prescribing task duration and technician quantities is provided on validated Coast Guard MPCs.

4. *Is the component available through the organization's supply chain?*

   **Answer:** Yes.

   **Explanation:** ALCO 251 diesel engine parts are currently available for purchase from the military stock system or original equipment manufacturer. Individual parts, components, assemblies, and subassemblies of the engine exist in the supply system in various quantities. The Surface Forces Logistics Center determines which parts are to be stocked for rapid access at Coast Guard Inventory Control Points.

   Nearly a decade ago, the original equipment manufacturer stopped producing parts for the ALCO 251 diesel engine. The Coast Guard soon discovered severe material
deficiencies with parts provided by the military stock system. These failures were
discovered during corrective maintenance responses to equipment casualties. The
government determined that suppliers were sourcing inferior parts from third-party
vendors and disposed of all stock. The Coast Guard engaged the original equipment
manufacturer and established a new supplier agreement to provide quality parts again.
This praxis recommends SFLC continue to monitor OEM parts agreements to ensure
sufficient parts remain available through the remainder of the sustainment phase.

5. Are special tools required and available?

Answer: Yes.

Explanation: The special tools required to complete all depot maintenance tasks are
available at designated MEC MATs. The costs associated with these tools are considered
sunk costs as they currently exist in the MAT inventory. Special tools are available for
purchase and are considered a neutral cost between resources due to the common price
and sole source.

6. Are depot maintenance facilities required and available?

Answer: Yes.

Explanation: Each cutter home port has a MAT facility. MEC MAT facilities are
considered a sunk cost due to their existence as a MAT facility for other cutter classes as
well (no new construction or alteration required). This determination aligns with
government facility utilization practices. Should the MAT be moved or decommissioned,
the facility would be repurposed for other government utilization.
7. Does the component present environmental impacts?

Answer: Yes.

Explanation: Diesel engines present environmental impacts. Fuels and lubricants are readily available in home ports (supply impacts). Handling and disposal of these materials are in accordance with state, local, and federal regulations (hazardous material impacts). Each home port is located on a Coast Guard Base with hazardous material control policies and resources available for both cutter and MAT use. Cutters have fuel and lubricating oil transfer and storage systems to facilitate liquid transfers. Crews are properly trained to complete flammable liquid transfers. MAT facilities are outfitted with approved parts cleaners for which routine maintenance and support is established through the Base. Liquid oily waste storage, transfer, and disposal are coordinated by cutter crews, and oily rag disposal is the responsibility of both cutter and MAT facilities in accordance with regulations. Units must continue training programs for hazardous material handling and disposal.

8.a. Do designated technicians exist in the organization?

Answer: Yes.

Explanation: D-level technicians are assigned to each cutter’s designated MAT. The Coast Guard’s model Famous Class MEC MAT is MAT Portsmouth, VA. MAT Portsmouth is properly staffed with military technicians (rank E4-E8) and 1 Chief Warrant Officer (CWO) supervisor.

4.3.3 Medium Endurance Cutter Economic Analysis

Table 4-14 displays labor rate calculations for MEC preventive depot maintenance
procedures. The table lists the MPC title, the cost for each level technician (military and non-military) and sum cost of each task by the resource. In brief, the Coast Guard is the lowest cost resource at $21,246.71 while non-Coast Guard technicians are estimated at $46,530.33, and a blend of 2 non-Coast Guard supervisors and 5 Coast Guard technicians estimated at $30,665.11.

Table 4-14: MEC Depot Maintenance Labor Rate Calculations

<table>
<thead>
<tr>
<th>Title</th>
<th>CG E8 Labor</th>
<th>CG E7 Labor</th>
<th>CG E6 Labor</th>
<th>CG E5 Labor</th>
<th>CG E4 Labor</th>
<th>CG GS13/Diesel Tech Labor</th>
<th>CG ALCO Local Tech Labor</th>
<th>CG FME Company Tech Labor</th>
<th>CG Total Labor</th>
<th>CG Total Labor</th>
<th>CG Total Labor</th>
<th>CG Total Labor</th>
<th>CG Total Labor</th>
<th>Blend Total Labor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbocharger Replace</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
</tr>
<tr>
<td>Lube Oil Pump Replace</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
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<td>$71.00</td>
</tr>
<tr>
<td>Aftercooler Inspect and Clean</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
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<td>$71.00</td>
<td>$71.00</td>
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<tr>
<td>Full Power Groom Inspection</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$71.00</td>
<td>$71.00</td>
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<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
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<tr>
<td>Bypass Valve Diesel Engine Inspect</td>
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<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$71.00</td>
<td>$71.00</td>
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<td>$71.00</td>
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<td>$71.00</td>
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<tr>
<td>Jacket Water Cooler Inspection</td>
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<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$71.00</td>
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<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
</tr>
<tr>
<td>Remove H/D and H/G Relief Valves for Testing</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
<td>$71.00</td>
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<td>$71.00</td>
<td>$71.00</td>
</tr>
<tr>
<td>Cylinder Head Replace* (Divided to single cylinder)</td>
<td>$0.00</td>
<td>$172.34</td>
<td>$142.00</td>
<td>$142.00</td>
<td>$142.00</td>
<td>$213.00</td>
<td>$213.00</td>
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<td>$213.00</td>
<td>$213.00</td>
<td>$213.00</td>
<td>$213.00</td>
</tr>
</tbody>
</table>

Since the Famous Class MEC is in the final decade of its life cycle, Coast Guard MATs have developed sufficient on-the-job training programs for newly reported personnel. The Navy provides ALCO 251 series engine training upon request, eliminating the need for the Coast Guard to develop training. All non-Coast Guard technicians addressed in this research have several decades of ALCO 251 experience and are certified master diesel mechanics or original equipment manufacturer’s technicians.

The results of Table 4-14 are visually depicted in Figure 4-5, MEC Depot Level Maintenance Labor Rate Column Chart.
Figure 4-5 visually depicts the variations in resource costs per task. The column chart shows that non-Coast Guard technician labor rates far exceed Coast Guard or blended labor rates for Aftercooler Inspect and Clean, Remove Main Diesel Engine Relief Valves for Testing, and Cylinder Head Replace tasks. The Biennial Main Diesel Engine Inspection is an outlier in which non-Coast Guard and blended maintenance teams are equally valued and exceed Coast Guard technician costs due to task complexity. These tasks present the greatest opportunity to maximize resource flexibility through blended teams comprised of two advanced non-Coast Guard technicians and five basic Coast Guard technicians. There is little risk in assigning all remaining tasks to Coast Guard MAT technicians as warranty work is not a consideration and technicians are readily available.
Unlike the NSC case study which modeled a program in the acquisition phase (predictive data), the MEC sustainment case study presents the opportunity to analyze historical MAT performance data for the MEC main propulsion diesel engine. This research collected and analyzed one year of maintenance performance recorded by MAT Portsmouth technicians. The data and its associated labor rate analysis is seen in Table 4-15, MEC Depot Maintenance Labor Rates for 1 Year MAT Performance.

A review of the total labor sums in Table 4-15 yields interesting results. Many of the tasks assigned to the MAT were corrective maintenance tasks not identified in the prescribed maintenance program found in Table 4-14, MEC Depot Maintenance Labor Rate Calculations. The analysis shows an estimated cost for each resource to complete the tasks based on recorded task duration and technician quantity data. The analysis discloses that cost differences between resources are actually greater than predicted with Coast Guard technicians estimated at $114,491.98, non-Coast Guard technicians at a significant $275,017.55, and a blended team at a moderate $153,718.74.
The column chart in Figure 4-6 reveals that several tasks should be reserved for Coast Guard technicians if possible to include Replace Cylinder Head, Fuel Rack Replacement, Replace MDE Aftercooler, Camshaft Replacement, Clean Jacket Water Cooler, Replace Jacket Water Cooler, and Repair Lube Oil Cooler. These tasks do not exceed Coast Guard MAT technician proficiency or capability.

The column chart also reveals that several tasks should be primarily assigned to a blend of technicians to include Main Diesel Engine Inspection and Diesel Engine Inspection Full Power Groom. Both tasks require strong technical proficiency, and the Main Diesel Inspection requires significant labor hours. A blended team takes advantage of a highly proficient non-Coast Guard technician for oversight and reporting of conditions while labor is reduced through the use of Basic level Coast Guard technicians. This model has been employed for the majority of the MEC’s sustainment phase with excellent results.
4.3.4 Medium Endurance Cutter Decision Analysis

The Famous Class MEC has been in service for nearly 38 years, and the maintenance program has matured in lockstep with the hulls. This praxis recommends that the Medium Endurance Cutter Product Line renew existing service contracts with non-Coast Guard technicians and continue tasking Coast Guard MAT technicians with as many D-level tasks as their capacity warrants.

As the MECs age, equipment obsolescence becomes more prevalent. The Product Line proactively engaged the original equipment manufacturer approximately a decade ago when supply issues began to impact fleet readiness. The original equipment manufacturer has responded positively to Coast Guard demands to date. The Coast Guard must ensure maintainers provide detailed feedback during task completion to ensure part quality remains sufficient.

Task data integrity is of utmost importance to any analysis. The analysis of the one-year MPC performance data revealed variation in entries without explanation. For example, some tasks durations doubled on occasion without explanation. A conversation with senior MAT technicians revealed that most of the task duration variation was influenced by unforeseen interferences with task completion. The increasing frequency of such delays increases the need to assign tasks to Coast Guard technicians whenever possible. Doing so provides a means of controlling labor costs, and equipment condition deteriorates with age.

Training needs are being met through extensive on-the-job training alongside senior Coast Guard technicians and non-Coast Guard master diesel engine technicians. The organization possesses a healthy MEC maintenance culture and a robust pool of
experienced technicians.

4.3.5 Medium Endurance Cutter Sensitivity Analysis

Labor rate breakeven ratios are depicted in Table 4-16, MEC Sensitivity Analysis Labor Rate Ratios and Table 4-17, MEC Historical Task Performance Sensitivity Analysis Labor Rate Ratios. The ratios show the least total cost difference between Coast Guard and blended maintenance teams whereas the greatest cost difference exists between non-Coast Guard and Coast Guard teams. This data can be used on a task-by-task basis to analyze the weight of resource cost impacts at resource selection.

The ratios indicate the highest and lowest financial risks between two resources for all tasks. High ratios indicate the greatest cost disparity between two assessed resources. These tasks are a logical starting point for resource selection as they pose the highest financial risk. However, it is highly discouraged to make resource selections based solely on estimated costs. Noneconomic factors must be weighed prior to understanding the risk associated with each selection.

Low ratios indicate little difference between estimated labor costs and provide leverage for strategic resource decisions based on total program risks. In most cases, the selection for low ratio tasks will default to the organization’s resources in order to realize the highest return on internal resource investments and free external resources for their dedicated tasks. This method may also provide schedulers with healthier resource environments as buffer periods will be less constrained for complex tasks and availability improved for unplanned maintenance events (corrective).
It is very important not to make decisions based solely on cost. For example, the ratios for Biennial Main Diesel Engine Inspection strongly indicate a preference for Coast Guard technicians but, as stated in the previous analysis, the technical oversight needed for the task requires the technical proficiency of a master diesel engine technician or original equipment manufacturer. Table 4-16, MEC Sensitivity Analysis Labor Rate Ratios (Planned Maintenance) and Table 4-17, MEC Historical Task Performance Sensitivity Analysis Labor Rate Ratios indicate the lowest ratio (best total labor cost) alignment between Coast Guard technicians and a blended model and the largest ratio between Coast Guard technicians and non-Coast Guard technicians. Several tasks require no advanced technicians which result in a 1.000:1 ratio between the blended model and Coast Guard technicians.
A one-way sensitivity analysis calculates the estimated cost of labor should planned maintenance tasks take less or more time to complete than the maintenance procedure card dictates. One-way sensitivity analysis for Medium Endurance Cutter labor resources is shown in Tables 4-18, 4-19, and 4-20. Each Table shows the calculation of various task duration multipliers for the total labor cost of Coast Guard (Table 4-18), Non-Coast Guard (Table 4-19), and Blended Team (Table 4-20) resources. Each table provides analysts with an estimated labor cost for each task experiencing various task duration changes.

The formula for calculating each cost estimate is found in Section 3.10 of this praxis.
The Tables serve as inputs to Figure 4-7, Medium Endurance Cutter One-Way Sensitivity Graph, which depicts the estimated total labor costs for each resource at various levels of program maintenance duration. Figure 4-7 reports input values (duration multiples) on the x-axis and the calculated consequence (program labor cost) on the y-axis (Clemen & Reilly, 2014). Figure 4-7 shows the cost of each resource increasing in a linear fashion in response to each duration increase. As maintenance durations increase, the estimated cost disparity between each resource becomes more pronounced. This
shows the growing levels of financial risk between resources as durations increase. The sensitivity graph shows a max cost estimate of $63,740.13 for Coast Guard technicians, $139,591.00 for Non-Coast Guard technicians, and $91,995.34 for a Blended Team. The dotted light blue line indicates a breakeven point ($63,740.13) for Coast Guard technicians against the other two resources and the dotted green line indicates a breakeven point ($91,995.34) for the Blended Team against Non-Coast Guard technicians. Figure 4-7 implies a lower financial risk (valued at $75,850.87) of choosing Coast Guard technicians over Non-Coast Guard technicians under conditions of task duration uncertainty. The financial risk is calculated by subtracting the lower cost resource from the highest cost resource.

\[
\text{Resource (1) estimated total labor cost - resource (2) total estimated labor cost = financial risk value}
\]

Figure 4-7: MEC One-Way Sensitivity Graph
Chapter 5. Discussion and Conclusion

The methodology successfully met the research objective: to identify an enhanced balance of Coast Guard technicians and commercial resources to reduce vessel maintenance life cycle costs and improve Coast Guard workforce proficiency.

The noneconomic analyses in both NSC and MEC case studies show that maintenance procedure cards (MPCs) require a minimum number of technicians to complete any one task. This praxis proposes a team of (2) advanced technicians and (5) basic technicians comprise a blended team. These are the maximum number of technicians required to perform any one task for either vessel maintenance program. The technicians comprise a maintenance team which can be composed of technicians from the Coast Guard, non-Coast Guard contractors, or a blend of both. The decision analyses show that the team of (2) advanced technicians and (5) basic technicians is best constructed of (2) non-Coast Guard advanced technicians and (5) Coast Guard basic technicians to maximize cost efficiency and reduce risk.

Both case study economic analyses calculated the Coast Guard technicians as the least expensive labor source, the non-Coast Guard technicians as the most expensive labor source, and a blended team as the median cost labor option. The blended option provides a combination of reduced risk, increased availability, and a greater return on organizational investments in personnel and infrastructure.

The Coast Guard will always require the ability to operate without impacting readiness in the event of a loss of non-Coast Guard technical support. This is especially true during national emergencies, times of war, or when operating in budgetary extremis
while in sustainment. The British Royal Navy learned this when recruiting shortfalls and
budget cuts created a substantial manpower shortage and a total dependency on external
resources for maintenance. Subsequently, the Royal Navy suffered a crippling loss of
readiness, capability, and mission effectiveness (USCG, 2016). U.S. Coast Guard crews
are now embedded with the British Royal Navy to rebuild organic capability and reduce
national defense risks. This is a significant example of how detrimental failed personnel
and maintenance philosophies can be to a maritime organization.

The research explored the feasibility of null hypotheses. Total dependency on non-
Coast Guard technicians is too costly and introduces an unacceptable level of risk. The
economic analyses heavily favored Coast Guard technicians (estimated the lowest cost
resource and maximized return on investment) and noneconomic analyses determined the
Coast Guard cannot afford to lose technical proficiency. These discoveries support the
hypothesis that an enhanced blend of maintenance resources will favor internal Coast
Guard technicians over contracted maintenance resources. This holds true in programs
based solely on Coast Guard or blended teams (2 advanced non-Coast Guard technician,
and 5 basic Coast Guard technicians) as both depend upon internal Coast Guard
technicians. The NSC economic analysis revealed the significant cost difference between
Coast Guard and non-Coast Guard maintenance resources (breakeven ratio of 2.63:1) due
to the high cost of original equipment manufacturer labor for complex technology still
existing on the upside of the technology curve.

There are limitations on several aspects of this research. The application of the
proposed LORA model is completely dependent upon the existence of valid maintenance
tasks data. The NSC depot maintenance tasks require a round of validation to improve the
estimation of technician labor hours.

The scope of a LORA can be significant when applied to complex systems. This LORA intentionally limited analysis to propulsion main diesel engines and avoided expanding the analysis to related systems (e.g. reduction gears, shafts, piping systems, clutches). This condition limits the ability of this praxis to provide an account of the total workforce required to maintain more than one system and therefore cannot be used to calculate final staffing requirements for maintenance support entities. This research also focused on a single level of equipment indenture and avoided decomposing the engines for the analysis of individual subsystems or components. Therefore, the research presents an excellent case for first iteration LORAs but further equipment decomposition and analyses is required in the execution of a complete LORA.

Limited organizational experience with LORA restricted the research. The absence of an example Coast Guard LORA increased the difficulty of this research. The sole Coast Guard LORA discovered in the course of this research lacked noneconomic analysis and inaccurately addressed military labor rates. The document was deemed sensitive by the Coast Guard which made it inaccessible for reproduction or inclusion in this praxis.

A notable limitation is the clear absence of industry guidance on LORA. The available literature is inadequate when considering the impact a properly completed LORA can have on a maintenance program. There is a notable absence of professional publications and academic research on the topic of LORA. This situation provides ample opportunity for continued research into the impact of LORA in public and private sectors.

This praxis provides the opportunity for continued research. This praxis does not present an estimation of the optimal number of MAT technicians required to complete
tasks on a routine basis where maintenance overlap exists and multiple teams are tasked simultaneously. Therefore, the potential for future work exists to determine if LORA has relevance to a manpower requirements analysis. Additionally, the opportunity exists to investigate multiple blended team configurations and determine the most efficient application for each.

This research can benefit the engineering management profession by providing a thorough level of repair analysis to estimate the cost of prescribed maintenance activities for complex systems. The praxis presents a framework and standard forms for the completion of analysis where none currently exist. The praxis also provides an example of the process of LORA in action which may educate and guide a novice analyst.

This research can also benefit existing equipment owners seeking to understand the true cost of maintenance programs. Applying the proposed model to the analysis of equipment provides an activity-based cost management perspective to the resourcing of maintenance programs, revealing potentially unseen relationships between maintenance tasks and resource costs.

Additionally, this research has the potential to initiate a change to reliability centered maintenance programs. As reliability programs gain traction and emerging technologies improve sustainment efforts, the value of LORA and associated RCM analyses increases. The Coast Guard is just one potential benefactor from the adoption of the proposed model. Completing a thorough LORA, with a strategic view of the organization and a tactical view of its assets, can inform procurement, design, deployment, sustainment, and retirement decisions for engineering managers in multiple industries.
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