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THESIS

OPTIMIZING MARINE CORPS SECONDARY REPARABLE MAINTENANCE

by

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The Marine Corps manages a centralized secondary reparable inventory of over 1,000 different items with an enterprise-wide retail value of more than $600 million. These secondary reparable items are those components and subcomponents deemed economical to repair based on their expected costs and life cycles. The current ad hoc procedure to determine how to replenish each damaged secondary reparable relies on coordination between multiple organizations using information from various sources and varies from location to location. Ongoing Marine Corps efforts aim to determine the effectiveness of the Centralized Secondary Reparable Management Program by analyzing the cost and quality of these repairs and assessing the current manning of Marine maintenance activities. This thesis develops optimization models to assist in the determination of how to conduct these component repairs in the timeliest and least costly manner. Results from the model demonstrate the value of the organizations currently integrated into the secondary repairable maintenance cycle. Additionally, the solution provides strong evidence to support repair policies based on national stock numbers and location, drastically reducing the complexity of the current ad hoc procedures.

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OPTIMIZING MARINE CORPS SECONDARY REPARABLE MAINTENANCE

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ABSTRACT

The Marine Corps manages a centralized secondary reparable inventory of over 1,000 different items with an enterprise-wide retail value of more than $600 million. These secondary reparable items are those components and subcomponents deemed economical to repair based on their expected costs and life cycles. The current ad hoc procedure to determine how to replenish each damaged secondary reparable relies on coordination between multiple organizations using information from various sources and varies from location to location. Ongoing Marine Corps efforts aim to determine the effectiveness of the Centralized Secondary Reparable Management Program by analyzing the cost and quality of these repairs and assessing the current manning of Marine maintenance activities. This thesis develops optimization models to assist in the determination of how to conduct these component repairs in the timeliest and least costly manner. Results from the model demonstrate the value of the organizations currently integrated into the secondary repairable maintenance cycle. Additionally, the solution provides strong evidence to support repair policies based on national stock numbers and location, drastically reducing the complexity of the current ad hoc procedures.

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LIST OF ACRONYMS AND ABBREVIATIONS

CLS	Contractor Logistics Support
EGEM	Enterprise Ground Equipment Management
GAMS	General Algebraic Modeling System
HQMC, I&L	Headquarters Marine Corps, Installations and Logistics
LOGCOM	Marine Corps Logistics Command
LSMC	Logistics Support Management Center
IMA	Intermediate Maintenance Activity
MEF	Marine Expeditionary Force
MOS	military occupational specialty
NSN	national stock number
RIP	Reparable Issue Point
ROME	Repair Optimization Materiel Evaluator
SECREP	secondary reparable component or subcomponent
SROM	SECREP optimization model for minimum TAT
SROM′	SECREP optimization model for minimum cost
SROM-PN	SECREP optimization model-policy by NSN for minimum TAT
SROM′-PN	SECREP optimization model-policy by NSN for minimum cost
SROM-PNL	SECREP optimization model-policy by NSN and Location for minimum TAT
SROM′-PNL	SECREP optimization model-policy by NSN and Location for minimum cost
TAT	turn-around-time
USMC	United States Marine Corps
VAMOSC	Visibility and Management of Operating and Support Costs

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EXECUTIVE SUMMARY

Valued in the hundreds of millions of dollars, the Marine Corps' enterprise-wide inventory of secondary reparables (SECREPs) consists of over 1,000 components and subcomponents for which repair is deemed economical. When using units experience SECREP failures, they exchange these damaged parts for working ones at their supporting establishments Reparable Issue Point, where Marines determine feasibility of repairs and then the method by which to repair or replace the damaged SECREP and replenish the local inventory. Current ad hoc procedures for determining the method of replenishment rely on coordination between multiple organizations using information from various sources and vary from location to location.

Further exacerbating the SECREP exchange process, recent force drawdowns reduced the number of mechanics and supporting personnel available to perform the repair of damaged SECREPs and other maintenance activities across the Marine Corps. In an effort to assess the effectiveness of the Centralized SECREP Management Program, Headquarters Marine Corps, Installations and Logistics chaired a working integrated product team focused on the quality of repairs conducted, the cost associated with those repairs and the current manning and organization of the Intermediate Maintenance Activities (IMAs), which conduct the SECREP repairs.

This thesis supports the efforts of the working integrated product teams through the development of linear and integer-linear programs of the SECREP optimization model (SROM). Based on historical maintenance data, SROM incorporates parameters for repair cycle times, military labor hours, maintenance failure rates and costs of repairs associated with each of three methods: IMA repairs, contractor logistics support repairs, and new procurement at wholesale values. With these parameters, SROM assigns each failed SECREP at each Reparable Issue Point (RIP) to a method of repair while minimizing either the turn-around-time or the cost of repairs while enforcing constraints related to the IMAs available manpower, budgets and percentage limitations prescribed in Section 2466 of Title 10, United States Code, Armed Forces.

Results from SROM show that the current manpower at the IMAs does not restrict the optimal solution and that the minimum cost solution assigns 80% of failed SECREPs to the IMAs. Furthermore, the results support establishing SECREP repair policies based on assigning one method to each SECREP, based on the identifying national stock number and the location of the RIP. Implementing these procedures streamlines the decision made at the RIPs to a simple look-up table while reducing the turn-around-times and annual costs. SROM's optimal solution, in accordance with this type of policy, reduce the average turn-around time by 14 days as compared to other policies. The optimal solution's annual cost of repairs hovers around half that of other feasible solutions and cost roughly $600 million less than newly procuring each failed SECREP.

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I. INTRODUCTION

The United States Marine Corps (USMC) maintains an inventory of Secondary Reparable components and subcomponents (SECREPs) valued in the hundreds of millions of dollars. The current ad hoc procedure to determine how to replenish each damaged SECREP relies on coordination between multiple organizations using information from various sources and varies from location to location. Further complicating the decision, the Committee on Armed Services (2011) restricts the amount of the repairs available for outsourcing through contracted support to a maximum of 50% of the annual funding. In order to review the effectiveness of the Centralized SECREP Management Program, the USMC Logistics Policy and Capabilities Branch formed a working integrated product team focused on analyzing the cost and quality of the repairs and assessing the current manning levels of maintenance activities. This thesis supports the working integrated product team's efforts with the development of optimization models to guide the assignment of component repairs. These models seek the timeliest and least costly solution while considering throughput capacities, manning levels and budgetary constraints.

A. BACKGROUND

1. Centralized Secondary Reparable Management

At the onset of fiscal year 2001, the Marine Corps achieved initial operating capability of its efforts to centralize the management of SECREPs. The initiative grew beyond an enterprise wide inventory and distribution system and began incorporating Contractor Logistics Support (CLS) into the repair of specified SECREPs. Unfortunately, with the Global War on Terrorism, efforts shifted and prevented the full implementation of centralized SECREP management. Then, in 2005, as a component of the Marine Corps Logistics Modernization effort, the Marine Corps published the Centralized SECREP Management initiative (USMC 2005). This initiative sought to revamp earlier efforts to reduce excessive stocks at local supply distribution points by establishing enterprise-wide inventory of SECREPs.

Then, in 2012, the Marine Corps published Marine Corps Order 4400.200, establishing the Coordinated SECREP Management Program. The program intends to increase equipment readiness and limit operational risk by optimizing the inventory of SECREPs across the force. Among a list of several tasks required for success of the Coordinated Secondary Reparable Management Program, the order tasks Headquarters Marine Corps, Installations and Logistics (HQMC, I&L) and Marine Corps Logistics Command (LOGCOM) to "establish and maintain policy," "review policy and provide guidance and oversight," "direct operational support at Reparable Issue Points (RIPs) for critical support functions" and "provide the Continuous Process Improvement of retail SECREP management through standardized data collection, performance measurement and analysis" (USMC 2012b).

As a part of the Continuous Process Improvement, Marine Corps Logistics Command and the Logistics Operations Analysis Division, HQMC, I&L are conducting a ground supply intermediate level capacity study analyzing the capacities of the Marine Corps' intermediate level supply organizations and the effectiveness of their current manning and processes. One particular aspect of this revolves around how the seven different RIPs manage SECREPs.

2. SECREP Maintenance Process

According to Marine Corps Order 4790.19 (USMC 2012a), the Marine Corps deems an item economical to repair if the associated costs and expected lifecycle fall below 65% of the item's unit price. When items or subcomponents of larger end items meet this criterion, the Marine Corps classifies them as SECREPs. Currently, the Marine Corps' SECREP inventory consists of over 1,000 different items, identified by their national stock number (NSN), which the Logistics Support Management Center (LSMC) collectively values at over $600 million (LSMC 2015). Under the construct of the Centralized SECREP Management Program, the supply battalions, associated with the general support combat logistics regiments within each Marine Expeditionary Force (MEF) manage these inventories, commonly referred to as "floats." When a supported unit possesses a damaged SECREP, they execute the following process:

> a. Removal
>
> The defective item is removed from the end item and taken to the supporting float by the owning or intermediate maintenance unit. Removal of any item is accompanied by turn-in documentation required by the float holder.
>
> b. Turn-In
>
> The defective item is checked for completeness and is exchanged for an on-hand, serviceable item. If an exchange item is not on-hand, the float holder accepts the defective item and provides the customer with a backorder receipt. Once the float holder receives the required item from its source, the item is issued to the customer. If several units have placed demands on the float holder for like items, the float holder issues the requested item based on the established priority of need. Priorities are assigned to all supply transactions in accordance with the guidelines contained in MCO 4400.16.
>
> c. Repair
>
> Defective items turned in to the float holder are sent to the maintenance battalion for repair and subsequent return to the float holder's stock. (USMC 2016)

As the float holder, the RIP coordinates with the LOGCOM site manager, if present, and the Intermediate Maintenance Activity (IMA) to determine if a requirement exists across the enterprise for the SECREP or if the IMA possesses a damaged SECREP in worse condition. If no requirement exists, and a more degraded part does not need replacement at the IMA, then the SECREP begins the disposition process. However, if a backorder exists in the enterprise or at a customer level, then the RIP seeks to replenish the damaged SECREP in one of three manners: repair by the local IMA, repair through CLS, or purchase of a new SECREP, from a designated source of supply, at wholesale value.

Sending the damaged SECREP to the IMA allows Marine maintainers to conduct the necessary repairs. Generally, the IMA provides the cheapest repair alternative; however, with the force restructuring, which began in 2012, reducing the total force to 182,000 Marines (Feickert 2014), the IMAs experienced reductions in their Table of Organization and Equipment. As a result of these reductions, "Officers In Charge of Intermediate Level Supply accounts have voiced concerns about not being able to adequately support the MEFs due to reduced manpower and increased requirements"

(Marine Corps University 2017). CLS provides a means to augment the IMA's maintenance capabilities. The repair time and cost of repairs at CLS facilities both fall under contract for select SECREPs. Limited to two thirds of the original unit price, these repairs provide a cheaper alternative than wholesale vendors provide but still cost more than IMA repairs. Compared to the IMA repairs, CLS turn-around-time (TAT) typically tends to take longer. However, the CLS TAT suffers less from variability and some suspect that the civilian master mechanics produce a better-quality repair. Finally, the purchase of a new SECREP theoretically results in the fastest replenishment, dependent on shipping times, but it costs more than both repair options.

B. IMA ORGANIZATION

The Marine Corps categorizes their ground equipment maintenance into two levels, field and depot (USMC, 2014). Depot level is the highest level and focuses on tasks such as major overhauls of principle end items. Due to the scope of the maintenance tasks conducted within this level and their high priority, depot level maintenance activities typically do not conduct SECREP repair. Within the realm of field level maintenance, using units conduct operational maintenance tasks such as preventative maintenance and basic replacement of damaged parts. While still within the field level of maintenance, intermediate maintenance tasks require additional training, equipment or facilities beyond those on the using unit's Table of Organization; SECREP repairs reside within this echelon of maintenance tasks. Due to the additional requirements, intermediate maintenance takes place at designated organizations, IMAs, in support of the using units. For this thesis, the IMAs considered are those collocated with the seven permanent RIPs as seen in Figure 1.

Figure 1. Force Laydown of RIPs. Adapted from unitedstatesmapz (2018).

For the support of a MEF, the Maintenance Battalion, which falls under the Field Service Support Group, conducts SECREP repairs. If supported units smaller than a MEF require support, then a scaled, task-organized maintenance detachment provides similar but limited repair capabilities. Doctrinally, the maintenance battalion within each MEF contains five companies as outlined in Figure 2. However, scaled down units only contain those organizations and capabilities required for their unique mission.

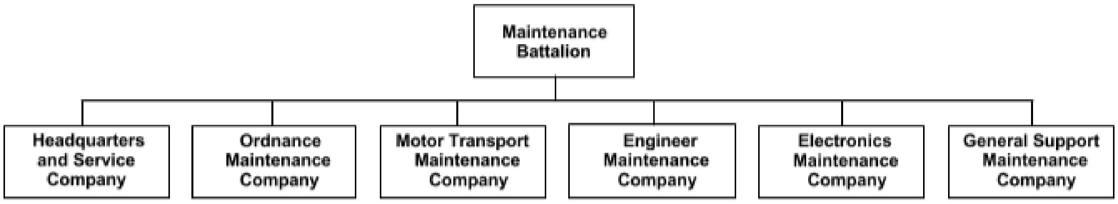

Figure 2. Maintenance Battalion Task Organization. Source: USMC (2016).

While all of the companies perform intermediate repairs on the end items within their respective expertise, the general support, electronics and ordnance maintenance companies are the only three companies, which also conduct SECREP repair. Due to the special equipment and environments required to conduct component repair on SECREPs, these three companies attempt to collocate with the supply points and RIPs.

General support maintenance companies contain several platoons and sections within them and of those, the sections under the Component Repair Platoon generally conduct the repair of SECREPs aligned to the components principle end item. With the sections under its charge, the general support maintenance companies repair SECREPs belonging to engineering equipment, motor transport equipment, amphibious assault vehicles, light armored vehicles, tanks and other fuel and electrical systems. Within the electronic maintenance companies, the radio, data equipment and micro-miniature repair sections handle the repair of SECREPs. While this mostly includes subcomponents of communications systems, it also includes repair of other parts or circuit boards belonging to non-communications major end items. Finally, the ordnance maintenance companies conduct repairs on SECREPs belonging to weapons systems outside of the capabilities of the ground support maintenance companies. Specifically, ordnance maintenance companies maintain the capabilities to repair subcomponents of infantry and precision weapons, artillery and electro-optics. While variations exist in the size of these sections and their individual capacities, the general capabilities and organization remain consistent across the IMAs. Marines in each section perform repairs based on their primary military occupational specialty (MOS) with some repairs (such as fuel systems or micro-miniature repairs) requiring additional training, as annotated on the Table of Organization by the billet MOS. This thesis focuses on the following MOSs within the aforementioned companies:

- Ground Support Maintenance Company
    - Engineering Equipment Electrical Systems Technician (1142)
    - Engineering Equipment Mechanic (1341)
    - Assault Amphibious Vehicle Repairer (2141)
    - Main Battle Tank Repairer (2146)

  - Light Armored Vehicle Repairer (2147)
  - Automotive Maintenance Technician (3521)
  - Fuel and Electrical Systems Technician (3524)[1]
- Electronics Maintenance Company
  - Ground Electronics Transmission Systems Maintainer (2841)
  - Ground Electronics Telecommunications and Information Technology Systems Maintainer (2847)
  - Micro-Miniature Repairer (8641)[2]
- Ordnance Maintenance Company
  - Small Arms Repairer (2111)
  - Towed Artillery Systems Technician (2131)
  - Electro-Optics Ordnance Repairer (2171)

C. OBJECTIVES AND SCOPE

This thesis develops multiple versions of the SECREP optimization model (SROM) which implements the required programming to assist Marines working at the seven permanent RIPs determine where to send damaged SECREPs, in order to minimize total duration of repairs and associated costs. SROM integrates key parameters, including TAT, individual labor hours, costs of repairs, and the expected number of failures, through the analysis of maintenance data collected between fiscal years 2014 and 2017, CLS contract information, wholesale prices, manning of the IMAs and Marine Corps staffing goals. By ensuring that constraints revolving around budgeting and available working hours are met, SROM details (by the SECREPs' individual NSN and the location of the RIP) the

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[1] Additional billet MOS for primary MOS (1142, 1341, 2141, 2146, 2147, 3521)

[2] Additional billet MOS for primary MOS (2841, 2847)

appropriate quantities of damaged components to repair or replenish by either the IMA, CLS, or wholesale vendors.

With further analysis of SROM’s results, planners gain insight into the optimal policies for ensuring timely and cost-efficient maintenance practices. Additionally, the incorporation of current tables of organization and staffing goals into SROM allows for an analysis of how effective the current IMA structure meets their assigned mission.

D. ORGANIZATION

Four additional chapters comprise this thesis: Chapter II provides background and insight from a literature review of related studies. Chapter III explains the assumptions made and the formulation of the linear and integer-linear programs developed. Chapter IV describes the implementation of SROM, the data, and discusses the results. Finally, Chapter V discusses conclusions and recommendations for extensions of this work.

II. LITERATURE REVIEW

Despite the existence of literature related to individual aspects of SROM, previous work does not completely encompass the methods used in or applied to the problem addressed in this thesis. While there are many related Marine Corps optimization applications, particularly in the aviation community or at the depot level with tools such as LOGCOM's Repair Optimization Materiel Evaluator (ROME), these applications tend to focus on either inventory or manning and scheduling of maintenance units. Additional research regarding the repair versus replacement decision provides insightful parallels; however, most of these applications take the perspective of lifecycle cost analysis and complement decisions made during acquisitions.

A. APPLICATION OF OPTIMIZATION IN THE USMC

1. Optimizing Inventory Management

Previous works done by Marines illustrate the application of linear programs to optimize inventories and supply chain management. Yorio (1988) provides one such example in his use of integer-linear programing to assist in the determination of the optimal stockage levels for repair parts for a Marine Air Ground Task Force. In his analysis, Yorio develops maximum likelihood estimates for the failure rates of 25 SECREPs common to a Marine Amphibious Unit based on historical maintenance records. An integer-linear program incorporates these estimates to optimize the overall probability of survival for critical pieces of equipment while ensuring the stocked parts do not exceed the available cargo space aboard ship. In addition to assisting logistics planners determine inventory levels, the associated low probabilities of success, which result from the model, highlight the need for higher prioritization of repair parts and logistical support during amphibious operations. Like SROM, Yorio's work incorporates historical maintenance data into an optimization model and centers around SECREPs. However, the spares model approach, which Yorio and many of those he references implement, incorporates penalties for stock-outs and focuses on finding optimal inventories rather than the optimal method for replenishing those with reduced stocks.

In an effort to improve the inventory control processes at Marine Depot Maintenance Command, Curling (2016) combines the use of optimization and discrete event simulation. He uses the critical part inventory optimization model to determine the respective quantities of parts to order for major equipment overhaul, while minimizing stock-outs subject to demand levels, safety-stock and budgetary constraints. He incorporates the optimization results into a discrete event simulation, which, based on historical data, simulates the assembly and disassembly of vehicles and equipment. Combining the two models allows the simulation to provide the current stock levels to the optimization model, which, in turn, supplies the quantity ordered to the simulation. During the validation of the interface between both models, Curling uses only six consumable items from 12 amphibious assault vehicles. Despite the limited scope, he demonstrates that by combining both models and tracking measures of effectiveness within the simulation, the integration of optimization and simulation serves as a valuable tool to guide decision makers. Curling's approach and others like it, such as those detailed by Pierskalla and Voelker (1976), address similar issues as SROM. Each model focuses on subcomponent repairs with the military and incorporating repair capabilities from historical data. However, these studies determine stockage of critical supplies and best practice order policies. While SROM currently does not incorporate simulation, adding the capability to an extension of SROM could provide a means to verify results over a long planning horizon.

2. Optimal Manning of Maintenance Personnel

Other uses of optimization in relation to USMC maintenance pertain to the appropriate manning of maintenance activities in order to meet mission demands. Goodwin (2016) develops an integer-linear program focused on appropriately assigning maintenance tasks to Marines working on F/A-18 Hornets. By analyzing historical maintenance and manning data, Goodwin establishes parameters for the labor hours required for Marines with the required skill sets, in the designated work centers, to conduct the appropriate repairs. The objective function seeks to maximize the number of ready aircraft by assigning the repairs to specific shops and ensuring that the labor hours used do not exceed the time available. Goodwin shows where overtasking occurs in the maintenance cycle and explores the benefits of adjusting manpower and maintenance days. These explorations illustrate how increases to available maintenance hours increase aircraft readiness yet still fail to maintain the required standards as aging aircraft continue to increase maintenance requirements. In a similar fashion, SROM relies on historical maintenance data to capture the required labor hours for Marines, in their respective organizations, to conduct repairs and also implements similar constraints for the limitations on repair capacity. While SROM does not specifically address the assignment of personnel to specific tasks, it does allow for an exploration of effects due to changes in staffing goals. Future extensions might look to expand SROM to incorporate this ability.

3. Repair Optimization Materiel Evaluator

Other uses of optimization in the military focus on appropriately scheduling maintenance and the development of control theory models such as those discussed in Cassady et al. (2001) and Pierskalla and Voelker (1976). Recently, LOGCOM capitalized on the use of big data analytics and optimization to improve depot-level ground equipment maintenance based on the large quantities of historical maintenance data available within the master data repository. In their brief "Big Data at LOGCOM," Bagley and Coleman (2017) discuss how the price and performance model uses this data to "identify optimal candidates for depot level maintenance" and "aid in the development of program objective memorandum budgets submissions." As a component of the price and performance model, ROME handles the optimization of depot level maintenance scheduling based on annual funding. By incorporating values that prioritize the necessity of repairs for items, as calculated by other components within the price and performance model, ROME "provides an optimal readiness repair plan for given budget constraints." With these verified, validated and accredited results, the model assists decision makers at LOGCOM in the development of an effective and defendable depot level maintenance plan and budget. Like ROME, SROM seeks optimal repair policies while considering fiscal constraints and facility capabilities. The two differ as SROM deals with replenishment of already failed SECREPs whereas results from ROME assist in the scheduling and budgeting of depot level repairs and overhauls for all ground military equipment, principle end items (e.g., tanks, amphibious assault vehicles, and medium tactical vehicle replacements) within the Marine Corps' inventory.

B. REPAIR VERSUS REPLACE

1. Applications Outside of the USMC

The repair versus replace decision aims to replenish damaged components in the most cost-effective manner. Dewey (2014) highlights the importance of this decision when discussing ground equipment maintenance in the Army's 1st Stryker Brigade Combat Team, 25th Infantry Division. Stationed in Alaska, the unit experienced longer than average delays in delivery of key components. After experiencing substantial budget cuts, the brigade analyzed maintenance trends and decided to conduct several maintenance tasks within their own organization, which doctrinally called for repair at higher echelon facilities or procurement of new components. By conducting the additional maintenance tasks and locally sourcing parts, the brigade experienced millions of dollars of saving within just a few months. Through their efforts, the brigade identified a trend within technical manuals and procedures to simply replace damaged components, which resulted in a negative trend in the abilities of younger mechanics to conduct basic repairs. While difficult to quantify, the decision to conduct critical component and subcomponent repairs vice replacing them increased the monetary savings and bolstered waning skillsets while affording the brigade multiple training opportunities.

While the 1st Stryker Brigade's decisions demonstrate the value of appropriate repair versus preplace decision-making, the methodology proved rather simple and less in-depth than typical optimization of repair and replacement research. Currently the Navy and the Air Force implement optimization in efforts to determine whether to continue to maintain aging ships or aircraft or purchase newer platforms. These approaches, similar to the model developed by Jondrow et al. (2001) and discussed by Keating and Dixon (2004), compare optimization results with cost estimates to assist in the acquisition of new platforms. Based on predictions from repair cost trends, these models seek the minimum cost to operate the aging system while maintaining the required levels of availability. A comparison between the resulting optimal costs and the estimated average lifecycle cost per year of the new technology provides insight to decision makers regarding when to replace systems. While the theory behind these works relates to the decision that this thesis addresses, the approaches rely more heavily on operational and sustainment cost estimation than historical analysis of the repair facilities capabilities.

2. Warranty Policies

Literature outside of the military provide examples of how repair versus replace optimization influences servicing of items under warranty. Iskandar and Murthy (2003) discuss how to develop and implement optimization models for two-dimensional warranty policies. They model failures on a hypothetical system using a gamma distribution and then seek the minimal servicing cost over the life of the warranty. Their model identifies, for each item, whether to repair or replace the item, based on the remaining duration of the warranty coverage. By incorporating different constraints, they illustrate how to represent and explore different company policies or business strategies and their effects on the optimal solution. While warranty repair or replace optimization aims to reduce the cost of maintenance, this example differs from the ultimate goal of SROM as industries using this strategy look at a limited time horizon only as long as the life of the warranty. Should extensions of SROM incorporate the quality of repairs associated with the different methods, analyzing a limited timeline versus the total life of the SECREP could lead to biased recommendations and less than optimal policies.

3. Total Life Cycle Analysis

Unlike the decisions made in industry for warranty policies, most repair versus replace research literature recommends the use of total lifecycle costs. Incorporating longevity of repairs over the product’s lifetime, allows the model to account for the potential of conducting a cheaper repair more frequently, which eventually outweighs the cost of replacement. This type of analysis becomes critical in competitive markets during the acquisition process. As discussed by Saranga and Kumar (2006) in their research on level of repair analysis, repair versus replace optimization helps validate operational and support cost analysis and assists with the planning of necessary supporting infrastructure in even the most complex, multi-echeloned maintenance architecture. Other potential benefits come from the analysis of systems of systems and the ability to identify which subcomponents warrant the designation of SECREP.

Brendecke (2016) presents an example of how to implement a lifecycle repair versus replacement optimization model for a complex system of systems. His model takes a Markovian approach, classifying the individual subcomponents of a system as new, old or broken. Within this cycle, new and old parts eventually transition states, based on specified probabilities, and become broken. Repairing parts transitions them to the "old" state while replacing them transitions them to a "new" state. A linear program, which seeks the minimum average lifecycle cost while considering the failure rates within each state and cost associated with each method of replenishment, produces the optimal repair versus replacement strategy. Considering the total lifecycle of a system of multiple subsystems differs this model from SROM. The implementation of such a strategy on the problem addressed by this thesis requires the simultaneous optimization of the Marine Corps entire ground equipment inventory, to include the principle end items and all SECREPs and consumable parts belonging to them. Current maintenance data does not provide the necessary information to accurately assess the expected longevity of all these items based on their respective methods of repair or replacement. Furthermore, Brendecke notes a dramatic increase in the time and computing power necessary to run his model as the evaluated system grows. For these reasons, SROM focuses solely on the SECREP decision process and statistics from historical data to deliver timely and appropriately scaled results to Marines working at the tactical level.

III. MODEL DEVELOPMENT

This chapter describes SROM, explains the assumptions made, and presents the formulations for the linear and integer-linear programs developed.

A. ASSUMPTIONS

This section details the assumptions required for the implementation of SROM.

1. Based on the current supported and supporting relationships within the USMC and current SECREP exchange procedures, failed SECREPs only receive IMA repairs at the IMA locations associated with the respective RIP. This prohibits SROM from assigning high-demand SECREPs to adjacent IMAs in the network even if they possess greater capacities for the required types of repair.

2. SROM only considers regular working hours and does not incorporate overtime or increased working hours due to procedures such as maintenance stand-downs.

3. SECREPs assigned to the IMAs undergo successful repairs and do so in the prespecified TAT.

4. SECREPs assigned to IMAs only require one MOS to conduct the repair and therefore do not sit in queues waiting for other sections of Marines to complete prerequisite repairs.

5. The enterprise wide inventory levels do not factor into SROM. This results in a closed system where all failed SECREPs are repaired or replaced and the disposition of parts damaged beyond economic repair is excluded from the model.

B. SECREP OPTIMIZATION MODEL

Under the assumptions stated in Section A, SROM optimally assigns the quantity of failed SECREPs from each location to one of the three methods of repair or replacement over the course of the models planning horizon. To accommodate potential policy variations, this thesis implements several versions of SROM. Versions differ between linear and integer-linear programs in order to reflect varying policy constraints. Each version of SROM relies on input parameters gathered from USMC historical maintenance records and the individual IMA's Table of Organization and Equipment to derive the optimal repair or replacement assignments.

1. SROM Formulation

This section describes the indices, sets, parameters, decision variables, and formulation for the linear program version of SROM. SROM relies on three sets of constraints and one additional non-negativity restriction. While this seems rather small, when considering the number of NSNs, RIP locations and methods of repairs, this equates to over 29,000 constraints and more than 20,000 decision variables. The introduction of the indexed sets helps to develop a formulation involving only feasible combinations of NSN, method of repair and location.

a. Indices

l – Location of RIP, for $l \in L$;

m – Method of repair (IMA, CLS, wholesale), for $m \in M$;

n – NSN of SECREP, for $n \in N$;

o – Occupational specialty of Marine, for $o \in O$.

b. Sets

L_o – set of locations in L that have occupational specialty o;

$M_{n,l}$ – set of feasible repair methods in M, available to RIP location l, for NSN n;

N_l – set of NSNs in N that can be repaired by an IMA at location l.

c. Parameters and [units]

$budget$ – Budget allowed for repairs during the period of study [\$];

$capima_{o,l}$ – Number of Marines with occupational specialty *o*, at location *l* [Marines]. Note: $capima_{o,l} = 0$ if $l \notin L_o$;

$cost_{n,m}$ – Cost of repairing NSN *n* using method *m* [\$];

$fail_{n,l}$ – Number of NSN *n* expected to fail over the period of study, at location *l* [items];

$imatime_{o,n,l}$ – Labor hours required for occupational specialty *o*, to repair NSN *n*, at location *l* [hours];

$tat_{n,m,l}$ – Turn-around-time for NSN *n*, using repair method *m*, from RIP location *l* [days];

$worklim$ – Limit on time for mechanics to work during the period of study [hours].

d. Decision Variables

$Q_{n,m,l}$ – Quantity of damaged items of NSN *n*, repaired by method *m*, from location [items].

e. Objective

$$\min \sum_{n} \sum_{l} \sum_{m \in M_{n,l}} tat_{n,m,l} Q_{n,m,l} \tag{1}$$

f. Constraints

$$\sum_{n} \sum_{l} \sum_{m \in M_{n,l}} cost_{n,m} Q_{n,m,l} \leq budget \tag{2}$$

$$\sum_{l} \sum_{n \in N_l} cost_{n,IMA} Q_{n,IMA,l} - \sum_{n} \sum_{l} cost_{n,CLS} Q_{n,CLS,l} \geq 0 \tag{3}$$

$$\sum_{m \in M_{n,l}} Q_{n,m,l} = fail_{n,l} \quad \forall n \in N, l \in L \tag{4}$$

$$\sum_{n \in N_l} imatime_{o,n,l} Q_{n,IMA,l} \leq capima_{o,l} worklim \quad \forall o \in O, l \in L \tag{5}$$

$$Q_{n,m,l} \geq 0 \quad \forall n \in N, l \in L, m \in M_{n,l} \tag{6}$$

g. Description of model

Equation (1) is SROM's objective function. It expresses the total aggregate TAT for all failed SECREPs. Equation (2) ensures that the total cost of all repairs remain below a desired budget. Solving SROM with different budgets shows the tradeoff between total TAT and the cost of repairs. Due to the requirements that services cannot contract more than half of their maintenance (Committee on Armed Forces, 2011), Equation (3) ensures that the costs associated with IMA repairs outweigh, or at least achieve parity with, those for CLS repairs. Each Equation (4) ensures that each failed NSN, at each location, is repaired or newly purchased. For those repairs conducted at the IMA, Equation (5) ensures that the total military labor hours expended by each MOS at each location does not exceed the available working hours. Finally, Equation (6) declares variable types.

2. SROM-PNL Formulation

The base version of SROM allows multiple methods of repair for each NSN, each location, and each combination of the two. However, if the desired policy seeks to limit the number of methods available based on these parameters, SROM no longer applies. Satisfying these types of conditions requires the adaptation of SROM from a linear program to an integer-linear program. The following alterations result in SROM-policy by NSN and location (SROM-PNL) which limits the number of methods available for the repair of each NSN at each location.

a. Additional Parameters

limmethod – Limits the number of methods available for repairing a designated SECREP.

b. Additional Binary Variables

$X_{n,m,l}$ – Indicates whether method *m* is used to repair NSN *n*, at location *l*.

c. Updated Constraints

With the introduction of binary variables, the following three additional constraints are introduced:

$$Q_{n,m,l} \leq fail_{n,l} X_{n,m,l} \quad \forall n \in N, l \in L, m \in M_{n,l} \tag{7}$$

$$\sum_{m \in M_{n,l}} X_{n,m,l} \leq limmethod \quad \forall n \in N, l \in L \tag{8}$$

$$\sum_{m \in M_{n,l}} X_{n,m,l} \geq 1 \quad \forall n \in N, l \in L \tag{9}$$

$$X_{n,m,l} \in \{0,1\} \quad \forall n \in N, l \in L, m \in M_{n,l} \tag{10}$$

d. Description of Model

Equation (7) ensures that at each location, each failed NSN is repaired or newly purchased through an available option. Equations (8) and (9) ensure that the number of methods used to repair each NSN at each locations is below the limit and at least one is assigned, respectively. Equation (10) ensures decision variables $X_{n,m,l}$ are binary.

3. SROM-PN Formulation

In the case of a more restrictive policy, SROM-policy by NSN (SROM-PN) implements the necessary changes to assign one method of repair to each NSN regardless of location.

a. Updated Binary Variables

Due to the fact that location no longer plays a role in the determination of the method, the location index is removed from the binary variable described in SROM-PNL resulting in the below binary variable:

$Y_{n,m}$ – Indicates whether method *m* is used to repair NSN *n*.

b. Updated Constraints

With the adjustment, Equation (4) is replaced with Equation (11) and Equation (7), (8) and (9) are replaced with a single equality (12).

$$Q_{n,m,l} = fail_{n,l} Y_{n,m} \quad \forall n \in N, l \in L, m \in M_{n,l} \tag{11}$$

$$\sum_{m \in M_{n,l}} Y_{n,m} = 1 \ \forall n \in N, l \in L \tag{12}$$

$$Y_{n,m} \in \{0,1\} \ \forall n \in N, l \in L \tag{13}$$

c. Description of Model

Equation (11) ensures that the each failed NSN is repaired or newly purchased through the method available for each respective NSN. Equation (12) ensures that one and only one method is available to repair each NSN. Equation (13) ensures decision variables $Y_{n,m}$ are binary.

4. Formulations for Cost Minimization

Developed in parallel with SROM, SROM-PNL and SROM-PN, three additional versions seek to minimize the cost of repairs without TAT restrictions. The minimum cost versions, denoted as SROM′, SROM′-PNL and SROM′-PN reflect the same policies and constraints as the parallel minimum TAT versions. The only differences come from the removal of Equation (2), the budget constraint, and the replacement of the objective function, Equation (1), with Equation (14).

$$\min \sum_{n} \sum_{l} \sum_{m \in M_{n,l}} cost_{n,m} Q_{n,m,l} \tag{14}$$

The creation of these three versions of SROM′ allow for the comparison of each policies minimum TAT and the overall minimum cost associated with each respective policy. From this point forward, mention of minimum TAT solutions and their applicable policy refer to optimal solutions from SROM, SROM-PNL and SROM-PN. Similarly, the mention of minimum cost solutions and their applicable policies refer to optimal solutions from SROM′, SROM′-PNL and SROM′-PN.

IV. IMPLEMENTATION AND ANALYSIS

This chapter discusses the implementation of SROM versions and the data, and presents an analysis of the results.

A. COMPUTER IMPLEMENTATION

This thesis uses General Algebraic Modeling System (GAMS 2018) version 24.8, a commercially available optimization software, to generate SROM and applies CPLEX 12.0 (GAMS 2016) to solve all versions of SROM. Scenarios analyzed in this research span a planning horizon of one year; however, adjusting the parameters allows for SROM to solve for shorter or longer timelines. Using a Microsoft Surface Pro 4 with a 2.4 GHz processor and 8 GB of RAM, CPLEX solves one iteration of SROM in about one second and solves the integer-linear program versions, SROM-PNL and SROM-PN in about two seconds each. This allows for the completion of 100 iterations across a spectrum of input data in less than 30 seconds with SROM, and in less than a minute and a half with SROM-PN and SROM-PNL. Each of the parallel minimum costs versions solved in equivalent times to their associated minimum TAT version.

B. DATA IMPLEMENTATION

The recent integration of Global Combat Support System – Marine Corps consolidated several outdated systems and allowed for the collection of data on every maintenance task conducted within the USMC. Recent efforts by LOGCOM and the Enterprise Ground Equipment Management (EGEM) department of HQMC, I&L, render these massive stores of maintenance data useful.

SROM relies on four data files maintained by both of these organizations to calculate input parameters: General Support Maintenance Raw Data (LSMC 2018), Logistics Integration Support Data Request (HQMC, I&L 2017), Visibility and Management of Operating and Support Costs (VAMOSC) Header Level Data (EGEM 2018), and VAMOSC Detail Level Data (EGEM 2018). While records indicate a total of 1,071 different NSNs, the data only contains the necessary and complete information for the incorporation of 1,057 NSNs into SROM. Table 1 displays the quantity of NSNs repaired by the IMA's, CLS or both.

Table 1. Breakdown of NSNs Repaired by IMAs and CLS.

Method of Repair	Total Number of NSNs	NSNs Repaired by Only IMA/CLS
IMA	884	511
CLS	560	187

1. Time Parameters

SROM requires time parameters associated with the TATs of each NSN for each method, and the military labor hours required for IMA repairs.

a. New Procurement TAT

As a commonly used estimate in the realm of USMC supply and maintenance, order ship time provides an estimate of the average number of days it takes for delivery of a part ordered by the RIPs. The General Support Maintenance Raw Data (LSMC 2018) contains more than 48,000 observations, gathered over the course of four years, classified as order ship times for the various NSNs represented within the data. As one of the SECREP replenishment methods considers the purchase of new SECREPs from a source of supply, the order ship time serves as an estimate for the TAT. As illustrated by Figure 3 and Figure 4 the order ship times remains fairly consistent between both the various RIPs and across time. However, analyzing the order ship time by NSN shows significant variability. The average standard deviation for order ship times by NSN hovers just below 80 days, indicative of the effects of outliers on the data. Since the "sample median is very insensitive to outliers" (Devore 2016, p. 32), the median order ship time provides an unbiased estimate for the TAT associated with procuring new SECREPs. For the 11% of the NSNs with no order ship time observations, a median TAT of eight days is assumed based on discussions with the Logistics Organizational Analysis Section within HQMC, I&L.

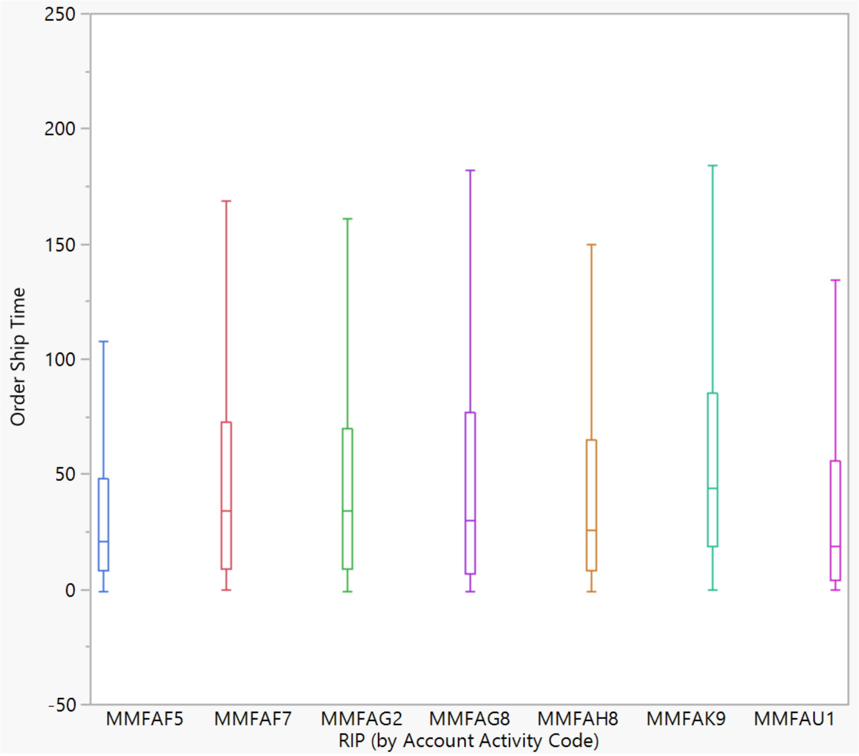


Figure 3. Box Plots of Order Ship Time Observations by RIP.

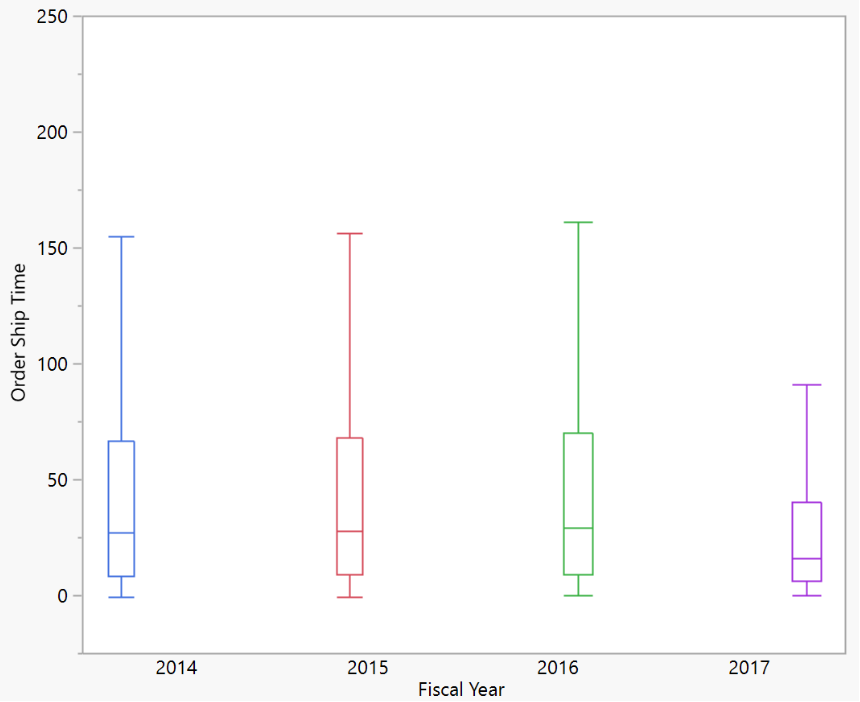


Figure 4. Box Plots of Order Ship Time Observations by Fiscal Year.

b. IMA TAT

Observations, within the General Support Maintenance Raw Data (LSMC 2018), classified as either successful repairs or washouts, represent the SECREPs on which the IMA conducted repairs. An estimate for the TAT, in days, results from calculating the number of days between the opening and closing of the service request for each of these observations. The data contains over 65,000 observations for the 884 different NSNs repaired by the IMAs over the past four fiscal years. Despite the large number of overall observations, the data contains less than five observations for roughly 55% of the 884 NSNs repaired by the IMAs. With so few observations for individual NSNs, the statistical significance of estimates suffers, and the assumption of normality becomes questionable. Additionally, significant variability exists between observations for some of the NSNs. Figure 5 shows this as several outliers exceed 150 days, with a maximum individual NSN TAT standard deviation of almost one year. Similar to the parameters developed for the source of supply TAT, the median of the time between opening and closing service request for each NSN, at each location, provides an unbiased estimate for the median TATs associated with repairing SECREPs at the IMAs.

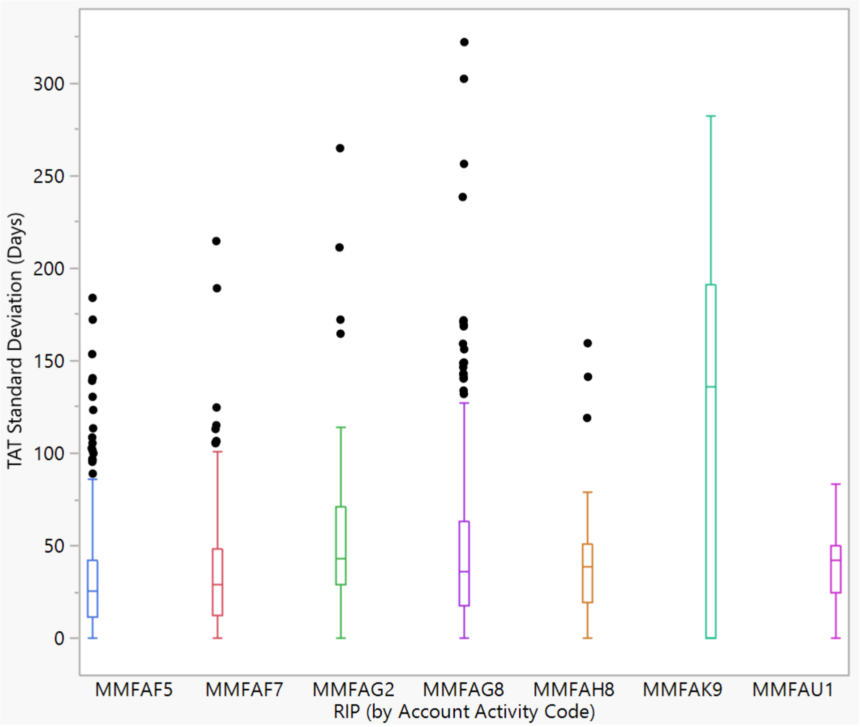


Figure 5. Box Plots of Standard Deviations for Individual NSN's TAT by RIP.

c. *CLS TAT*

In 2002, Raytheon began repairing SECREPs for the USMC and the company continues to do so today with the most recent renewal contract beginning in 2016. The Logistics Integration Support Request Data (HQMC, I&L 2017) consists of nearly 23,000 observations on the 560 different SECREPs repaired by Raytheon. With a standard deviation, across all NSNs, of 47 days, and difference between the mean and median of just over 11 days, the TAT estimates associated with CLS repairs suffer the least from variability as compared to IMA repair and new procurement. Figure 6 and Figure 7 show that the CLS TATs remain consistent across both location and year. Despite the reduced variability, similar to the General Support Maintenance Raw data, the estimates for CLS TAT suffer from small sample sizes. Of the 560 NSNs repaired via CLS, 46% of these NSNs contain less than five observations. Not wanting to falsely assume normality, the estimates for the CLS TAT result from finding the median for each combination of NSN and location.

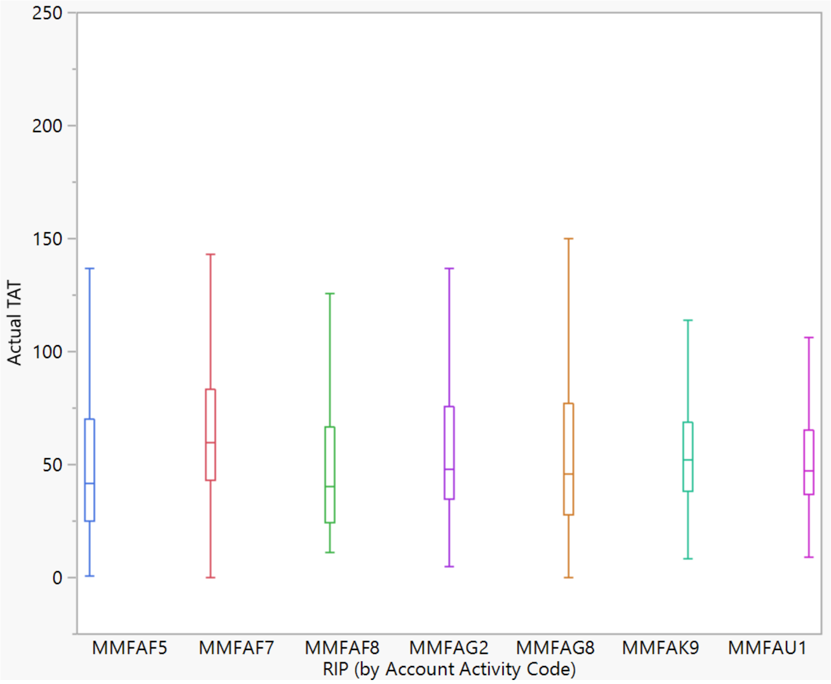


Figure 6. Box Plots of CLS TAT by RIP Location.

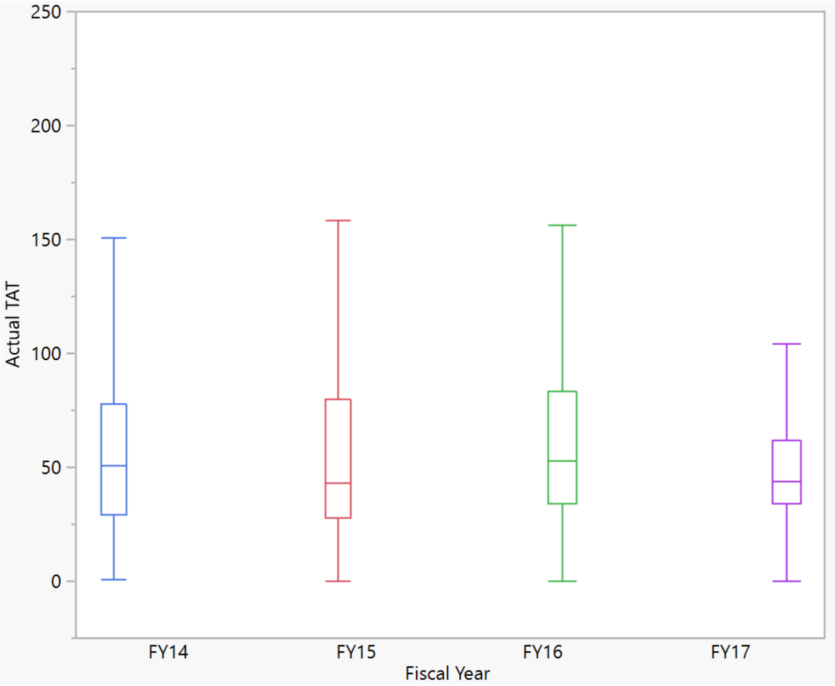


Figure 7. Box Plots of CLS TAT by Year.

d. Military Labor Hours

While the VAMOSC Header Level Data (EGEM 2018) contains over 1.8 million observations for maintenance tasks conducted between fiscal year 2014 and 2017, these observations include non-SECREP items. After filtering the data to only contain SECREPs, just over 85,000 relevant observations remain. Unlike the IMA and source of supply TAT information derived above, the military labor hours, captured in the header level data, do not suffer from large variability. While some NSNs require thousands of military labor hours to complete, Figure 8 shows that the upper quartile of observed military labor hours falls well below five hours with 90% of the repairs requiring less than ten military labor hours. Because of this tight interval, the mean of the military labor hours for each NSN and IMA location serves as the parameter, incorporated into SROM, for the required number of labor hours to conduct the necessary IMA repair.

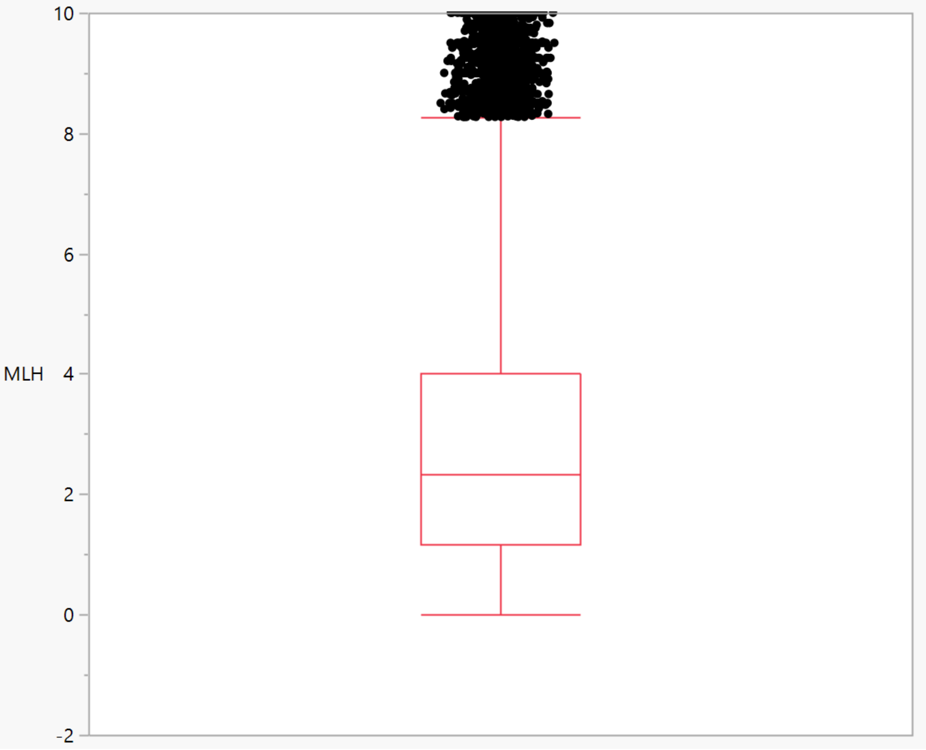


Figure 8. Box Plot of Military Labor Hours for IMA Repairs.

2. Cost Parameters

New procurement costs reflect the wholesale, unit price of each respective NSN according to the Defense Logistics Agency. Unlike these costs, the cost associated with IMA and CLS repair require estimation based on the provided data.

a. IMA Repair Cost

The VAMOSC Detail Level Data (EGEM 2018) provides information about all of the smaller consumable and repairable parts associated with the service requests contained in the VAMOSC Header Level Data (EGEM 2018). For example, if a SECREP in the VAMOSC Header Level Data requires five parts to repair it, then the VAMOSC Detail Level Data contains five observations, all with the same service request identification number linking them to the SECREP under repair. Each of these observations contains the unit price of the part required for repair and a SECREP multiplier. The SECREP multiplier applies a factor of either one, for consumable parts used, or two thirds for SECREPs used. This does not apply to the SECREP under repair. The SECREP multiplier simply assists in the cost estimating of any subsequent SECREPs required for repair of SECREPs in the VAMOSC Header Level Data to which the service request relates. Multiplying each unit price by the SECREP multiplier and then summing those values by service request identification number provides an estimated cost of repair for each service request. Categorizing these by NSN and then averaging the cost produces the estimated cost of IMA repair used by SROM. Of note, these repair costs include neither the labor costs associated with Marines' pay nor the overhead associated with keeping USMC facilities running.

Unfortunately, while the VAMOSC Detailed Level Data contains over 2.5 million observations, after completing the calculations it becomes apparent that of the 884 NSNs repaired by the IMAs, no associated cost data exists for 408 of these NSNs. With 46% of the SECREPs on which the IMA conducts repairs missing cost data, further analysis determines the cost parameters associated with those missing values. The SECREP multiplier follows the VAMOSC Business Rules (EGEM 2017), assuming that SECREPs cost two thirds of their wholesale unit price. This relates to the USMC standard of 65% of wholesale unit price (USMC 2012) for determining whether to classify an item as a

SECREP or not. While using two thirds of unit price to fill in all of the missing values provides a defendable upper bound, further analysis of the SECREP repair costs shows that for the SECREPs with sufficient repair cost data, the median hovered closer to 9% of unit price while the mean rounds to 15% of the SECREPs unit cost. In light of this information, missing cost estimates assumed the more conservative of the two statistics with a value of 15% of their respective unit price.

b. CLS Repair Costs

Despite the fact that contracts limit the price of CLS repairs, occasionally these repairs incur additional costs and the data does not show any cases where repairs cost less than the contracted price. Roughly 90% of the CLS repairs do not incur any additional costs; however, when additional costs do occur, those additions average roughly 60% of the contracted price. To account for this, the average approved total for the repair of each NSN serves as the estimate for the CLS cost incorporated into SROM.

3. Throughput and Capacities

a. Throughput

RIPs and other USMC supply and maintenance activities commonly use a maintenance failure rate to estimate inventory demands. The maintenance failure rate represents the average number of SECREPs, by NSN, exchanged at a given RIP each month. As a commonly understood estimate of SECREP demand within the Marine Corps, this thesis relies on observations, within the General Support Raw Data (LSCM 2017), classified as maintenance failure rates for determining the expected number of failures for each combination of NSN and RIP. Summing the monthly maintenance failure rates within each fiscal year and then averaging the yearly estimate results in the expected number of failures per year for each NSN at each RIP. If no maintenance failure rate observation exists within the data, then that NSN and RIP combination assumes the expected value of zero failures per year.

b. IMA Capacities

SROM calculates the IMA's capacity by considering the number of working hours performed by a Marine each week, assumed to equal 40 hours, and the number of Marines, with an MOS of interest, assigned to each of those IMAs. Looking at each IMA's Table of Organization and Equipment allows for the determination of the on-hand quantity of those Marines with the appropriate MOSs within the designated shops, as described previously in Chapter I. Table 2 displays the on-hand quantities at each IMA by MOS, except for Blount Island Command, where extremely limited maintenance capabilities and data observations lead to an assumption of IMA repairs not providing a viable alternative. Applying an 80% staffing goal to the on-hand quantities for active units, and 15% availability to the on-hand quantities for reserve units, produces the IMA capacities incorporated into SROM.

Table 2. Quantity of On-Hand Marines at Each IMA by MOS.

	RIP Nomeclature/Account Activity Code					
MOS	III MEF/MMFAF7	CLB-3/MMFAG2	I MEF/MMFAG8	TECOM/MMFAH8	MARFORRES/MMFAK9	II MEF/MMFAF5
1142	6	3	3	4	16	3
1341	14	5	9	18	24	10
2111	7	9	14	5	34	14
2131	2	4	7	4	12	6
2141	11	4	24	16	16	26
2146	6	0	4	17	12	12
2147	10	0	26	10	16	32
2171	20	5	26	14	50	26
2841	31	7	56	25	62	61
2847	32	3	44	13	46	49
3521	40	4	15	42	34	19
3524	11	0	9	10	12	8
8641	10	0	10	5	16	10

C. ANALYSIS

All three models, SROM, SROM-PNL, and SROM-PN, and their parallel minimum cost versions, result in feasible solutions for the data provided by EGEM, LSMC and HQMC, I&L. Analysis of results from each model and the comparisons between them illustrate the tradeoffs between TAT and cost, the effects associated with implementing certain policies and the impacts of altering manning at the IMAs.

1. SROM and SROM-PNL

The baseline run of SROM determines the optimal methods of repair for over 60,000 individual SECREP failures expected across all seven RIPs in one year. This particular run does not attempt to accommodate specific policy restrictions but rather seeks the unrestricted optimal solution. Despite this aim, with the collected data, the resulting optimal solution assigns only one method to each NSN at each location. SROM-PNL produces an equivalent optimal solution. Minimizing cost also results in equivalent solutions between SROM′ and SROM′-PNL. Like the minimum TAT solutions, the minimum cost solutions assign only one method to each NSN at each location. Upon completion of the optimization, a script in SROM writes two tables, similar to Figure 9, which display the optimal assignments for either the minimal TAT or the minimal cost. The values within the table represent the percentage of the failed SECREPs optimally assigned to each method of repair at each RIP.

NSN	Location	IMA	CLS	SOS
1010012579961	MMFAK9	0%	100%	0%
1010012579961	MMFAU1	0%	100%	0%
1010012579962	MMFAF5	100%	0%	0%
1010012579962	MMFAF7	100%	0%	0%
1010012579962	MMFAG2	0%	0%	100%
1010012579962	MMFAG8	100%	0%	0%
1010012579962	MMFAH8	N/A	N/A	N/A
1010012579962	MMFAK9	0%	0%	100%
1010012579962	MMFAU1	0%	0%	100%
1010012581473	MMFAF5	0%	0%	100%
1010012581473	MMFAF7	100%	0%	0%
1010012581473	MMFAG2	100%	0%	0%
1010012581473	MMFAG8	0%	0%	100%

The results from SROM reflect the percentage of the expected number of failures, for a given NSN at each location, assigned to each method of repair. N/A values represent zero expected failures for the specified NSN at that location. This sample only displays 13 rows, whereas the full file contains 7,400 rows.

Figure 9. Sample of Results from SROM Optimizing TAT.

Comparing the optimally assigned methods between the minimum TAT solution and the minimum cost solution reveals that of the 2,832 combinations of NSNs and locations, with the number of expected failures greater than zero, 58.9% of them use the same method. These particular NSN and location combinations show particular promise for an established policy based on NSN and location as they provide the best solution regardless of the decisions maker's intent to reduce cost or repair cycle times.

To identify the tradeoffs between repair costs and TAT, we run SROM several times, starting with a budget equal to the minimum cost resulting from SROM′ and relax the budget constraint until the minimum TAT remains unchanged. While the cost of replacing all failed SECREPs at wholesale prices equates to roughly $790 million, the minimum TAT cost less than half of that.

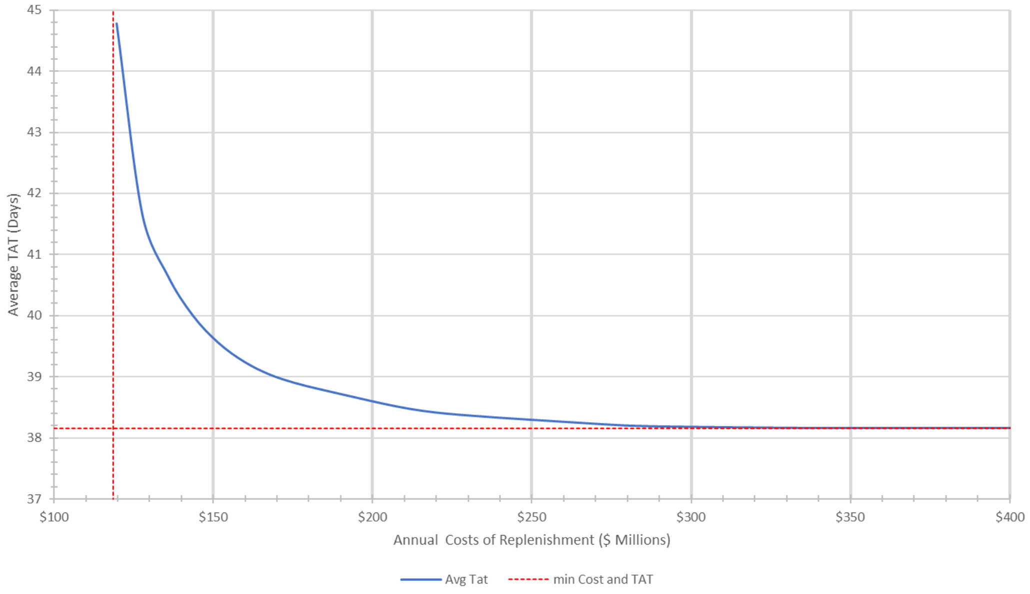


Figure 10. Tradeoffs between Average TAT and Annual Cost of Replenishment.

Figure 10 illustrates the reduction in TAT subject to an increase in budget. While the minimum TAT, 38.15 days on average, results in a cost of roughly $362 million, the minimum cost, just below $118 million, results in a TAT of 46.95 days on average. Despite the fact that additional costs lower the TAT, the return on the investment diminishes quickly. At more than three times the cost, the minimum TAT only reduces the average TAT by roughly 19% as compared to the minimum cost solution.

Further analysis of both the minimum cost and TAT solutions provides insight into the methods assigned and the differences in the workloads assigned to each method based on the respective model (SROM or SROM′). Figure 11 illustrates that as annual cost of repairs decreases between the minimum TAT and minimum cost solutions, the amount of work assigned to the IMAs increases.

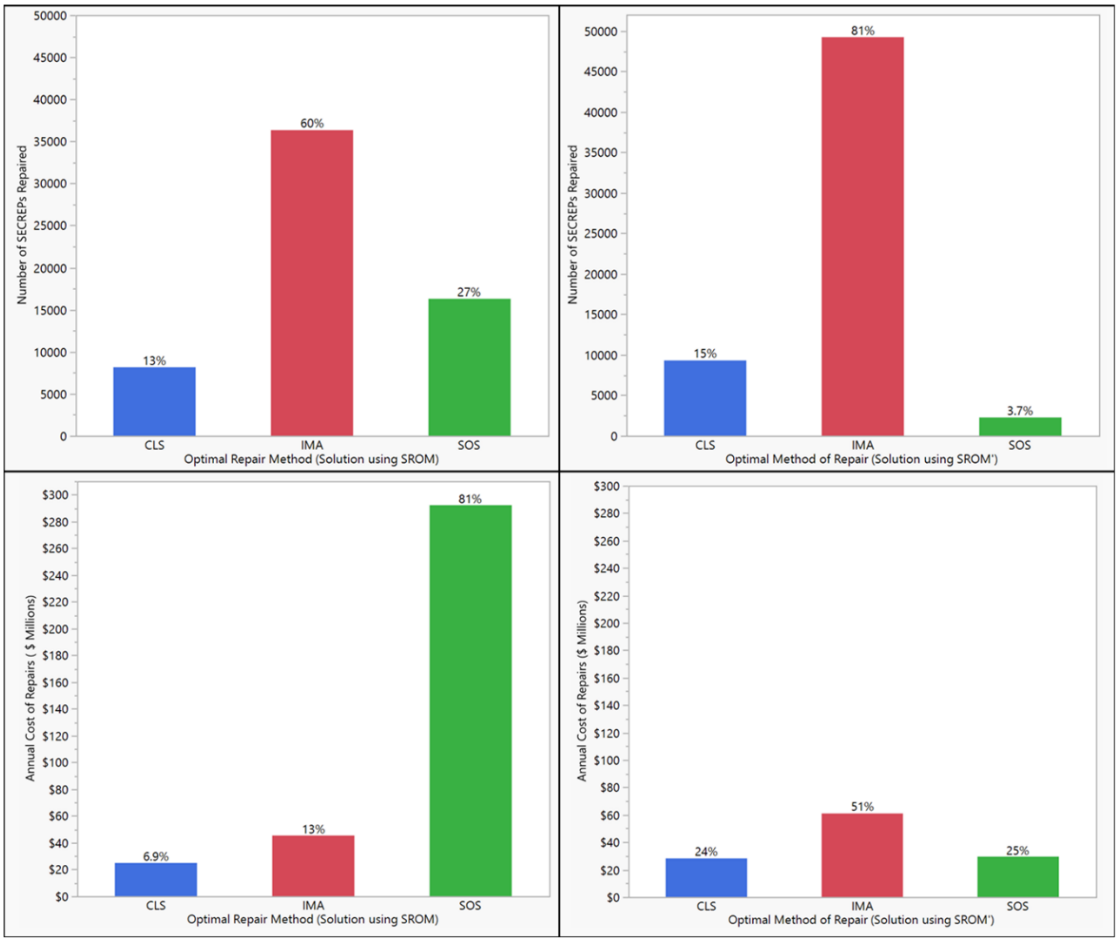
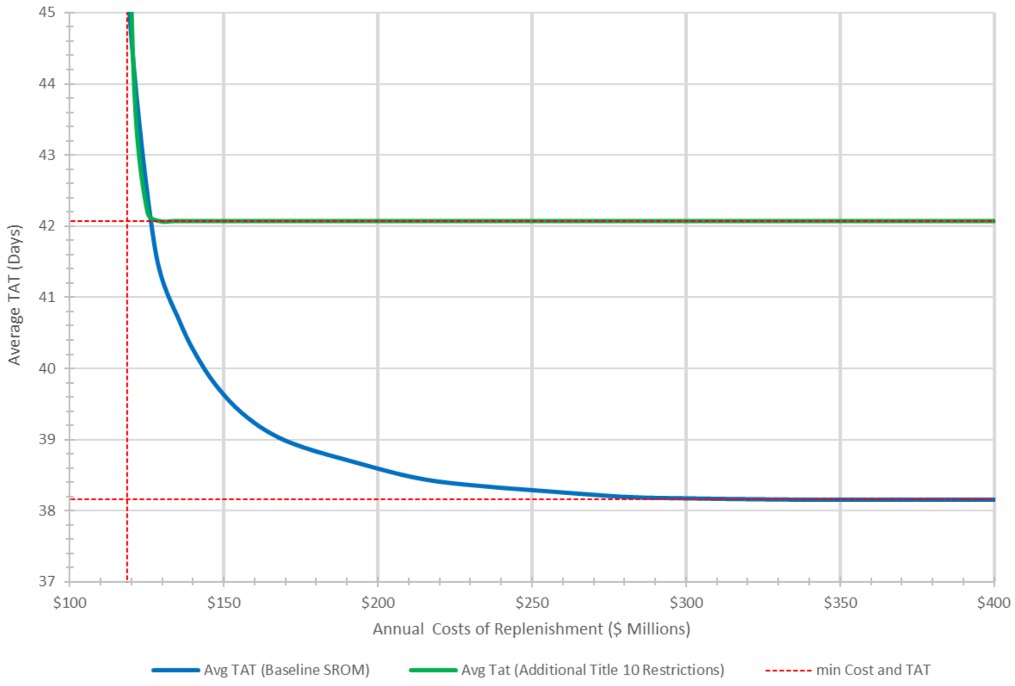


Figure 1. Comparison of Optimally Assigned Methods between Minimum TAT and Minimum Cost Solutions Using SROM and SROM′, Respectively.

Both the minimum cost and the minimum TAT solutions honor the percentage constraint enacted by the Committee on Armed Forces (2011). As implemented, the cost of contracted repairs may not exclude the cost of IMA repairs. However, a possible interpretation of the Committee of Armed Forces (2011) would require IMA costs to be at least 50% of total costs (inclusive of CLS, IMA, and new procurement). This interpretation eliminates options with reduced TAT at increased budgets. Figure 12 compares the minimum TAT solutions, as subject to the more restricted Title 10 constraint, to those which result from the baseline run of SROM. The additional restrictions increase the minimum TAT to 42 days, on average, at an annual cost of roughly $126 million; however, SROM′ results in the same minimum cost.



The baseline run of SROM satisfies Title 10 constraints, where CLS repair costs cannot exceed IMA repair costs (cost of new procurement are excluded). The run with additional Title 10 restrictions considers a case where IMA repairs account for at least 50% of the total repair costs (inclusive of CLS, IMA and new procurement).

Figure 2. Comparison of Minimum TAT between the Baseline and a More Restricted Interpretation of Title 10.

2. SROM-PN

While the least constrained version suggests the optimal solution aligns with SECREP maintenance policies by NSN and location, policies based solely on NSNs, regardless of location, provide simplicity to the decision makers and those enforcing the policies. Due to the assumption that Blount Island Command only replenishes failed SECREPs by CLS repair or new procurement, the analysis of SROM-PN does not consider SECREPs from this location. Failure to remove the Blount Island Command observations from this run eliminates the possibility of IMA repairs from all facilities, as the solutions generated by SROM-PN require consistency across locations for each NSN. The exclusion only removes 2% of the expected failures, reducing the number of failed SECREPs assigned by SROM-PN to just under 59,000.

Compared to the results from SROM-PNL, policy imposed by SROM-PN dramatically increases the optimal solutions for both TAT and cost. Figure 13 shows a comparison between the results from both models. If implementing SECREP repair policies based on NSN alone, the minimum average TAT equals 55.18 days, roughly 1.5 times larger than the minimum average TAT achieved by the policies based on NSN and location. The NSN based policy performs substantially worse when considering annual cost of repairs as well. Compared to the minimum cost achieved by SROM′ and SROM′-PNL, the minimum cost derived from SROM′-PN costs more than five times as much while the cost associated with the minimum TAT performs even worse.

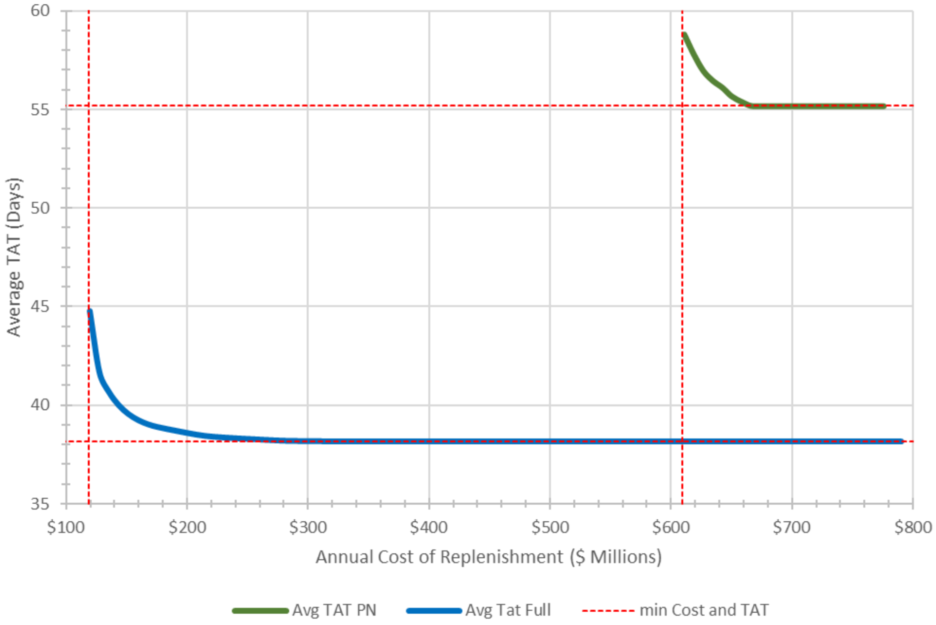


Figure 3. Comparison of the Annual Cost versus TAT Curves of SROM-PNL and SROM-PN.

Further degrading the validity of a repair policy by NSN, neither the minimum cost nor minimum TAT solutions allow for IMAs to account for 50% of the total repair budget but rather only provide solutions limiting the contracted repair cost to less than those associated with IMA repairs. By relaxing SROM-PN through the removal of Constraint (3) (requiring at least equal IMA and CLS expenditure), the optimal solution decreases the average TAT by 2.5 days and the annual cost by nearly 64%. This relaxed run of SROM-PN fails to enforce Title 10 (Committee on Armed Forces 2011); however, it allows for the range of work conducted by CLS to rise from 1.4% to 38% when minimizing TAT, and from 1.8% to 54% when minimizing cost. Despite the cost and time savings resulting from the relaxation of funding percentage constraints, the SROM-PN optimal solutions still result in average TATs nearly 14 days longer and at more than twice the cost as SROM′ and SROM′-PNL. Due to these reasons, SECREP repair policies strictly aligned to the NSN do not appear to provide a reasonable solution to SECREP repairs in the USMC.

3. Manpower and Other Insights

Since SROM relies on the MOSs working within the IMAs to determine capacity, categorizing the SECREPs by each of these MOSs provides a reasonable means to understand the employment of the IMAs capabilities as they relate to the solutions from each model. The slack associated with Constraint (5), which ensures the labor hours required to conduct repairs assigned to the IMAs does not exceed the working hours available to the IMAs, represents the amount of unused resources at the IMAs. The available time depends on the number of Marines on hand, the number of working hours per Marine per week (40 hours assumed in this analysis) and the number of weeks worked in a year (52 weeks assumed in this analysis). Based on the assumed values, a single Marine provides over 2,000 hours of work or roughly 87 days of continuous work. When looking at the average slack in labor hours per Marine, based on solutions resulting from SROM, a substantial proportion of the available working capacity remains unutilized. Figure 14 illustrates the changes in unused labor hours per Marine associated solutions from SROM as the budget decreases from the cost associated with the minimum time TAT to the minimum cost from SROM′. Similar to the results seen in Figure 11 where the restriction of the budget led to increased assignments of IMA repairs, the slack in the IMA’s labor hours decreases as the cost of repairs approaches the minimum cost solution and increases as TAT shrinks.

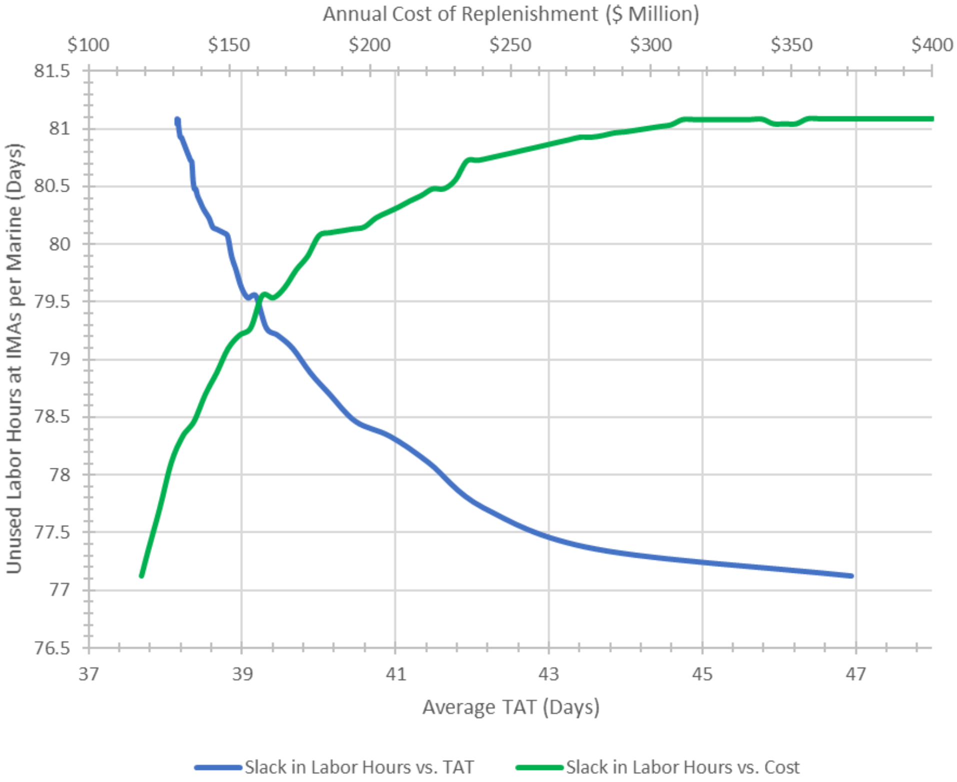


Figure 4. Effects of Annual Cost of Replenishment and Minimum TAT on Total Unused Labor Hours at the IMAs Based Solutions from SROM.

Large amounts of slack associated with labor hours, consistent across all MOSs and locations, mean that the capabilities of the IMAs do not restrict the optimal solution when seeking either minimum time or minimum cost. The proportion of unused labor hours to available labor hours suggests that reducing the available labor hours to 10-20% of their original values does not change the results of SROM or SROM′. However, none of the models used within this thesis incorporate stochastic processes in the determination of TATs. Blindly assuming that these slack values support drastic reductions in manpower ignores the principles of queueing theory and the likely increases to TAT as manpower decreases. These results merely promote further exploration with analytic tools focused on manpower and the assignment of work within existing organizations, which exceed the scope of this research.

V. CONCLUSIONS AND RECOMMENDATIONS

This thesis provides an optimization tool to assist Marines and decision makers with the management of the USMC's Centralized SECREP Management Program. The SROM minimizes the TAT and the cost of repairs by optimally assigning damaged SECREPs to available methods of replenishment based off historical maintenance data. Implementing SROM and adopting policies supported by SROM's solutions decreases the variability in the USMC's current ad hoc procedures for determining how to repair SECREPs, stresses the importance of USMC organic maintenance capabilities, and improves readiness while helping to reduce costs.

A. CONCLUSIONS

1. Collection and Usability of Data

The transition to Global Combat Support System – Marine Corps provides the USMC with troves of data regarding maintenance and supply transactions. While recent efforts across the USMC attempt to make this data useable, gaps still exist in the data. The fact that nearly half of the data, which spans four years, contains samples of less than five observations and missing values associated with costs, labor hours, and TATs implies room for improvement in the data collection itself or that additional information, still prime for harvesting, exists in the current collection of data. Failure to dedicate the necessary attention and resources to these improvements degrades the ability to effectively apply operational and informational sciences toward challenges in the USMC's current and future operational environments.

2. Value Added by IMAs

While recent trends increasingly rely on contracted support, the IMAs provide a valuable and integral service in supporting the USMC's enterprise wide inventory of SECREPs. Analyzing solutions derived by SROM reveals that more than 60% of the workload falls on the IMAs when minimizing TAT. As available funding decreases, this percentage eventually increases to a point where SROM assigns more than 80% of repairs to the IMAs at the lowest feasible cost. While intuitive that the USMC's organic maintenance capabilities provide the most cost-efficient alternative, this analysis shows that they provide the greatest contribution to the timeliest solution as well. Excursions with SROM, which explore options without IMAs, result in an increase of two weeks to the average TAT at more than double the annual cost. The capability for the USMC to organically repair SECREPs provides a necessary service to maintain enterprise-level inventories, the removal of which critically hinders maintenance efficiency.

3. Recommended Repair Policies

Setting standard procedures and policies simplifies the repair process by reducing the number of case-by-case decisions required and adding stability to the system. This thesis explores different possible policy restrictions, from none at all to assigning one method to each NSN, regardless of location. Service wide policies, based solely on NSN, perform the worst as they virtually remove IMA repairs. However, SECREP repair policies based on individual NSNs and the supporting unit's location provide the least expensive and timeliest feasible solutions. The analysis reveals that with these policies in place, 60% of the assigned methods of repair remain the same between the minimum TAT and minimum cost solutions. Enacting such a policy creates standard procedures for those SECREPs with consistent optimal repair methods between the minimum TAT and minimum cost solutions. For the other 40% of the SECREPs, a simple determination as to whether the failed SECREP causes a customer or inventory backorder reveals the appropriate method between the two objectives.

B. RECOMMENDED FUTURE WORK

1. Stochastic Optimization

Current versions of SROM are deterministic. This limits the parameters to non-parametric estimates and does not look at the enterprise-wide SECREP exchange and repair scheduling process from a queueing perspective. The VAMOSC data (EGEM 2018) contains the serial numbers associated with each individual SECREP and as data grows over time, the ability to track the individual subcomponent allows for the estimation of distributions for not only TAT and failure rates, but also the quality of the repairs conducted by each repair method. Determining these distributions and implementing a stochastic version of SROM would provide a means to analyze the repair versus replacement decision based on the total life cycle cost of SECREPs. While these calculations require more computing power and typically require more advanced and expensive software to run, the extended horizon and considerations allow for validation of the suggested policies and also help reevaluate whether or not each NSN warrants classification as a SECREP.

2. Incorporating Discrete Event Simulation

If future work develops a stochastic version of SROM, then integrating discrete event simulation further elevates the insights available from SROM. A plethora of previous research details how to incorporate discrete event simulation into optimization modeling. By interfacing the simulation with SROM, the user gains an ability to assess how the proposed policies perform with more detailed modeling of the processes involved. If designed so that the optimization model and simulation feed information to each other, the effects of adjusting capabilities and increasing the stress on the system become more apparent.

3. Deeper Analysis of Manpower

This thesis briefly explored the effects of altering the capabilities of the IMAs. While these results show that the constraints of available labor hours do not impede current IMA repairs, SROM relies on the staffing goal to determine capability and does not account for the additional taxes on the IMA’s manpower, such as the Fleet Assistance Program, or additional tasks related to annual training requirements. Fully exploring the effects of changes to the task organization and manning levels warrants further analysis focused directly at optimizing the manpower and skill sets at each supporting establishment. Incorporating queueing theory into a manpower focused optimization model would provide essential feedback regarding changes to manning, levels of training and the correlation between these factors and fluctuations in repair cycle times.

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