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OPTIMIZING MARINE CORPS FORCES RESERVE INSPECTION STRATEGIES

by

Michael Lugo Jr.

June 2020

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The Marine Corps Forces Reserve (MARFORRES) is trained, equipped, and organized to provide operational tempo relief support and enable the active-duty force during peacetime and wartime. This requires that MARFORRES remains in a constant state of readiness to activate at a moment’s notice to support the active-duty Fleet Marine Force. To ensure readiness, MARFORRES executes a series of inspections on its reserve units. We focus on MARFORRES G-4’s Supply and Maintenance Analysis Teams (SMAT) inspection program, which conducts extensive analysis of a unit’s Supply and Maintenance sections. In the last seventeen years, MARFORRES G-4 has seen several variations of SMAT in hopes of optimizing its resources to better execute its mandate to perform internal inspections. SMAT’s current construct is not operating up to the expectation of MARFORRES G-4 leadership. We address this by analyzing the value and management of MARFORRES’ limited resources. We use a multi-period mixed-integer linear program to maximize the total inspection value over a three-year time period, while satisfying various resource and budget restrictions. As a result, we inform MARFORRES on both the value of inspectors on SMAT and the resolution of resources based on commodity sections. Our analysis expands MARFORRES G-4’s decision space affording the ability to study effects on SMAT inspection value given deviations in resource and budget allocations.

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OPTIMIZING MARINE CORPS FORCES RESERVE INSPECTION STRATEGIES

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ABSTRACT

The Marine Corps Forces Reserve (MARFORRES) is trained, equipped, and organized to provide operational tempo relief support and enable the active-duty force during peacetime and wartime. This requires that MARFORRES remains in a constant state of readiness to activate at a moment's notice to support the active-duty Fleet Marine Force. To ensure readiness, MARFORRES executes a series of inspections on its reserve units. We focus on MARFORRES G-4's Supply and Maintenance Analysis Teams (SMAT) inspection program, which conducts extensive analysis of a unit's Supply and Maintenance sections. In the last seventeen years, MARFORRES G-4 has seen several variations of SMAT in hopes of optimizing its resources to better execute its mandate to perform internal inspections. SMAT's current construct is not operating up to the expectation of MARFORRES G-4 leadership. We address this by analyzing the value and management of MARFORRES' limited resources. We use a multi-period mixed-integer linear program to maximize the total inspection value over a three-year time period, while satisfying various resource and budget restrictions. As a result, we inform MARFORRES on both the value of inspectors on SMAT and the resolution of resource based on commodity sections. Our analysis expands MARFORRES G-4's decision space affording the ability to study effects on SMAT inspection value given deviations in resources and budget allocations.

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

AC/S	Assistant Chief of Staff
CGI	Command General Inspection
CMC	Commandant of the Marine Corps
CMR	Consolidated Memorandum Receipt
DASF	Due and Status Files
FSMAO	Field Supply and Maintenance Analysis Office
FY	Fiscal Year
ForO	Force Order
FRAAP	Force Readiness Activation Assessment Program
FTE	Full Time Equivalent
GAMS	General Algebraic Modeling System
GFC	Ground Force Commander
GCSS-MC	Global Combat Support System - Marine Corps
HQMC	Headquarters, Marine Corps
I-I	Inspector-Instructor
LERT	Logistics Enhancement Readiness Team
MCAAT	Marine Corps Administrative Analysis Team
MMT	Maintenance Management Tool
MARFORRES	Marine Corps Forces Reserve
MRTC	Materiel Readiness Training Center
MSC	Major Subordinate Command
OIC	Officer-In-Charge
OPLAN	Operational Plan
PSU	Preferred Sourcing Unit
SMAT	Supply and Maintenance Analysis Team
SNCOIC	Staff Non-Commissioned Officer-In-Charge
SL-3	Stock List- Level 3
USSOCOM	United Sates Special Operations Command

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EXECUTIVE SUMMARY

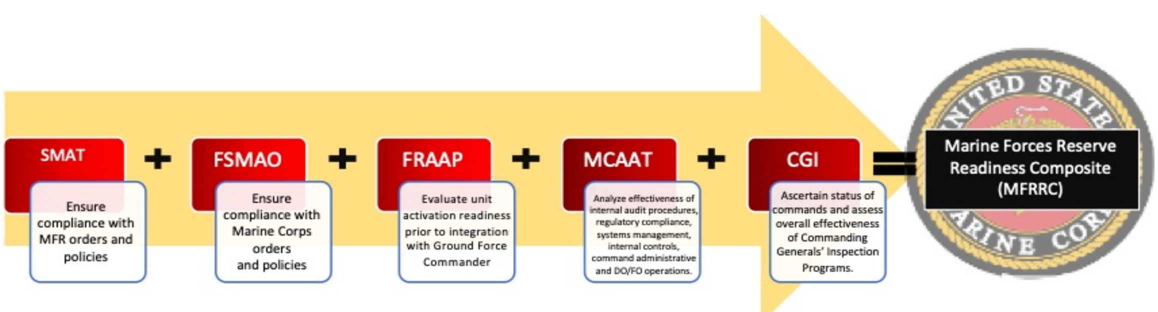
Within the last seventeen years, Marine Corps Forces Reserve (MARFORRES) G-4 has seen several variations of the Supply and Maintenance Analysis Team (SMAT) inspection program in the hopes of optimizing its resources to better execute its mandate to perform internal inspections. The current construct is not operating up to the expectation of MARFORRES G-4 leadership and the SMAT subject matter experts (SME) (SMAT, interview with author, January 22, 2020). We seek to address this by analyzing the value and management of MARFORRES' limited resources.

We introduce two multi-period mixed-integer linear programming (MILP) models, each of which seek to maximize the total inspection value of units selected for inspection while balancing associated resource requirements, distancing constraints, and budgets. The first linear program, MILP(1A), shows the effects of manpower restrictions on unit selection using a homogenous inspector (unspecialized in commodity section). The second, MILP(1B), is used to analyze how resource availability affects the problem using heterogenous inspectors (specialized with particular commodity section expertise). We use current SMAT policy as the foundation of our analysis with emphasis on the requirement to inspect all major units (those Mechanized Allowance List, or property book holding units). Finally, we analyze two cases: implementation of SMAT policy and deviation from current policy. Each theme provides insight into the effect of MARFORRES resources on total inspection value, and as a byproduct, inspection coverage.

Using MILP(1A) under SMAT's current policy, we find MARFORRES cannot meet policy requirements with five homogenous inspectors. However, we see large inspection value increases as we add additional inspectors. In particular, a sixth inspector will inspect all major units and increase total inspection value. An additional inspector shows a 4.1% increase in inspection coverage. This seventh inspector is a 14.3% increase in total inspection value. While we increase in inspection value as we increase budget, we find diminishing returns in the change of inspection value as we add more than seven inspectors.

Using MILP(1B) under SMAT's current policy, we find that if MARFORRES has less than 50% of its available resources, they will not inspect all major units, thereby not meeting policy requirements. In this three-year period with 50% of MARFORRES' total available resources, MARFORRES can inspect a total of 79 units, where 45 of these are major units and the remaining 34 units are subordinate. In this data instance, we find MARFORRES peaks in the number of units selected with 75% of their total available resources. This increases the number of units selected to 90 units (45 major units and 45 subordinate units) which is a 4.6% improvement in inspection coverage.

In our analysis, we focus on MARFORRES' SMAT inspection program. However, we can map any of MARFORRES' current inspection programs to our model with slight changes to set definitions and re-defining resource quantification as it pertains to the inspection. In generalizing our model, we propose a composite function, similar to the depiction in Figure ES-1, that analyzes various MARFORRES inspection program data to gain greater insight into resource management among inspection programs. Theoretically, the model would produce a score based on optimized values for each inspection program of interest to MARFORRES, which would result in what we call a Marine Force Reserve Readiness Composite (MFRRC). This MFRRC would inform the MARFORRES Commander on the health of his or her units, while speaking to inspection value and resource management in MARFORRES.



The figure is the proposed composite function that involves using the generalization of the SMAT analysis model to analyze each of MARFORRES' inspection programs.

Figure ES-1. Marine Forces Reserve Readiness Composite (MFRRC) Function

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To my wife, Karry: you have been there through it all. Your patience, love, and support gives me the strength to push through all of the challenges that come our way. Thank you for standing by me every step of the way through both the good and the bad.

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I. INTRODUCTION

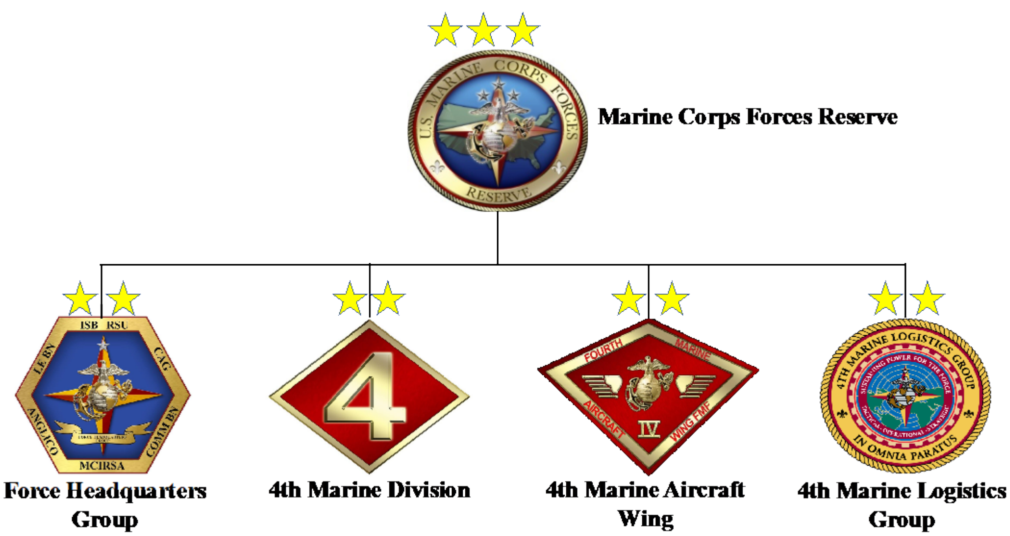
In this chapter, we discuss the background surrounding our analysis. We start with a brief introduction into Marine Corps Forces Reserve (MARFORRES) and its organization, followed by the organization and mission of MARFORRES G-4. We then discuss MAFORRES specific inspection programs with emphasis on Supply and Maintenance Analysis Team (SMAT) inspections. We provide a brief history of SMAT, the various inner workings of SMAT from unit selection to inspection preparation, and finally the execution of an inspection. We end this chapter with a discussion of the scope of the problem as it pertains to our analysis.

A. MARINE CORPS FORCES RESERVE BACKGROUND

Marine Corps Forces Reserve is the United States Marine Corps reserve component comprised of approximately 38,500 (as of 2017) Marine Reservists and Sailors assigned to various units located throughout the United States (Department of Defense [DOD], 2020). As of fiscal year 2020, there are 256 currently activated units. Per its mission statement, MARFORRES is trained, equipped, and organized to provide "operational tempo relief" support and enable the active duty force during peacetime (United States Marine Corps Reserve [USMCR], 2020). In times of war, the Marine Reserve Force augments and reinforces the active duty force in all domains of warfare, executes contingency operations, supports national emergency operations, and conducts community service (USMCR, 2020).

MARFORRES' organizational structure is built analogously to a Marine Expeditionary Force. At the top of the organizational structure, exists the Command Element where a three-star Commander of MARFORRES leads his forces. Under the Commander of MARFORRES is the Executive Director, the Chief of Staff, the Vice Chief of Staff, the MARFORRES Sergeant Major, and the Command Master Chief. Amongst the MARFORRES Commander exists the General/Special Staff and the Major Subordinate Commands (MSC). Under the General/Special Staff exists the G-1 Administrative and Personnel Section, G-2 Intelligence, G-3/5 Operations and Plans, G-4 Installations and

Logistics Section, G-6 Communications, Command Inspector General, and the G-8 Requirements Section. The Command Element is further broken down into Deployment Processing Commands, Environmental Services Division and Detachment, Marine Corps Band, and Reserve Support Units. The MSCs are 4th Marine Aircraft Wing, 4th Marine Division, 4th Marine Logistics Group, Force Headquarters Group, and Force Headquarters Group, as shown in Figure 1 (USMCR, 2020).

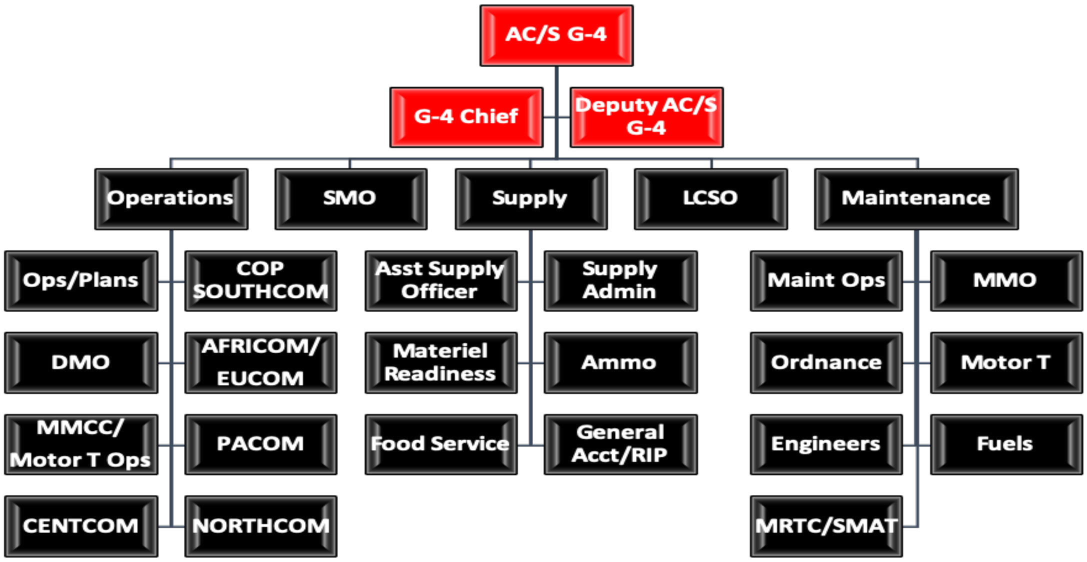


This chart displays the organizational structure of Marine Forces Reserve (MARFORRES). MARFORRES, based out of New Orleans, is further broken down into four components: Force, Headquarters Group, 4th Marine Division, 4th Marine Aircraft Wing, and 4th Marine Logistics Group. Each of these components is led by a two-star General.

Figure 1. Organizational Chart of Marine Corps Forces Reserve

B. MARINE CORPS FORCES RESERVE G-4

Understanding the structure of MARFORRES, we shift focus to MARFORRES G-4. Currently, MARFORRES G-4 is organized as shown in Figure 2:



This provides the breakout of Marine Forces Reserve (MARFORRES) G-4. At the very top is the Assistant Chief of Staff G-4 with his Deputy Chief of Staff and G-4 Chief. Under the G-4 Staff lives five sections of MARFORRES G-4: Operations, Security Management Office (SMO), Supply, Logistics Coordination Office (LCSO), and Maintenance.

Figure 2. Organizational Chart of Marine Forces Reserve G-4

Its mission statement is to:

> plan, coordinate, and provide policy, guidance, and oversight in the areas of supply, ammunition, food service, maintenance, distribution management, and strategic mobility to support training and maintain force readiness posture in order to provide ready, relevant, and responsive reserve forces capable of augmenting and reinforcing active forces for employment across the full spectrum of crisis. (USMCR, 2020)

MARFORRES G-4 is accountable for the logistical operations and welfare of its reserve elements as it pertains to the support of Marine Corps and its active force. Periodic inspections of its units are conducted to ensure compliance with MARFORRES and Marine Corps orders and policies. We will focus on MARFORRES G-4's Maintenance Section, where the Supply and Maintenance Analysis Team exists, while studying the inspection capability the team provides MARFORRES.

C. INSPECTION PROGRAMS PERTAINING TO MARINE CORPS FORCES RESERVE

The Marine Corps directs several inspection programs that evaluates and assesses the state of its units to ensure it remains a force in readiness. These inspection programs range from ensuring compliance with Marine Corps orders and policies to inspecting a Command's ability run the various unit-led programs that exist in the Corps (e.g. Equal Opportunity, Sexual Assault Prevention and Response, Voting Assistance Program). The execution of these inspections varies with time; some being conducted on an annual basis, while others occur every three years. In addition to these Headquarters, Marine Corps directed inspections, which apply to the entire Marine Corps, MARFORRES is required to execute additional inspection programs that ensures its units are adhering to the various existing reserve orders. Reserve units must remain in constant state of readiness to activate at a moment's notice to support the active-duty Fleet Marine Force- these inspection programs aim at guaranteeing that. We will provide a brief introduction to the various inspection programs under MARFORRES' purview in the next chapter, but we focus on the Supply and Maintenance Analysis Team Inspection Program and the associated data provided by MARFORRES G-4 in our analysis.

D. INCEPTION OF SUPPLY AND MAINTENANCE ANALYSIS TEAM (SMAT)

MARFORRES is mandated by Headquarters, Marine Corps (HQMC) to establish an internal inspection program that ensures reserve units comply with both Marine Corps and MARFORRES-specific orders and policies. Initially, MARFORRES intended to use Field Supply and Maintenance Analysis Office (FSMAO) to satisfy this mandate; however, this did not meet HQMC's intent (SMAT, interview with author, January 22, 2020). In 2002, the Logistics Enhancement Readiness Team (LERT) program was created. Its intent was to assess the effectiveness of existing MAFORRES orders, policies, and processes being tracked under the Logistics Automated Information System, while providing guidance to units with respect to current logistics and readiness instructions (SMAT, interview with author, January 22, 2020). LERT's purpose was to inspect and educate units in order to influence efficient and effective combat service support procedures and processes. LERT Teams fell directly under the purview of the Assistant Chief of Staff (AC/S) G-4 and visited units on a triennial basis by conducting formal analysis, or informally garnered by the requesting unit (Assistance Visits). Formal analysis resulted in a report of the unit's deficiencies and recommendations of which copies were forwarded to the

Inspector-Instructor (I-I) Officer-In-Charge, the AC/S G-4, AC/S G-7, and the unit's Major Subordinate Command (SMAT, interview with author, January 22, 2020). The unit was required to provide a corrective action plan to the AC/S G-4. Depending on the severity of the deficiency, the LERT Team re-inspected units to ensure corrections were made. Contrarily, Assistance Visits were informal in nature. No report was produced; however, the LERT Team was required to provide corrections and recommendations to noncompliant items found.

Between 2013 and 2014, MARFORRES evolved from the LERT Inspection Program to the Supply and Maintenance Analysis Team (SMAT) inspection program. The SMAT program provided similar capabilities as the LERT program (SMAT, interview with author, January 22, 2020). Units were formally inspected on a triennial basis to which a formal report was established and sent to the I-I Staff, AC/S G-4, and the MSCs. Units with deficiencies were required to provide corrective action plans and time estimates as to when they would be compliant. Units and MSCs were offered site assist visit (informal inspections) capabilities to enhance efficiency and effectiveness and were only executed if a formal request by the unit was initiated (SMAT, interview with author, January 22, 2020).

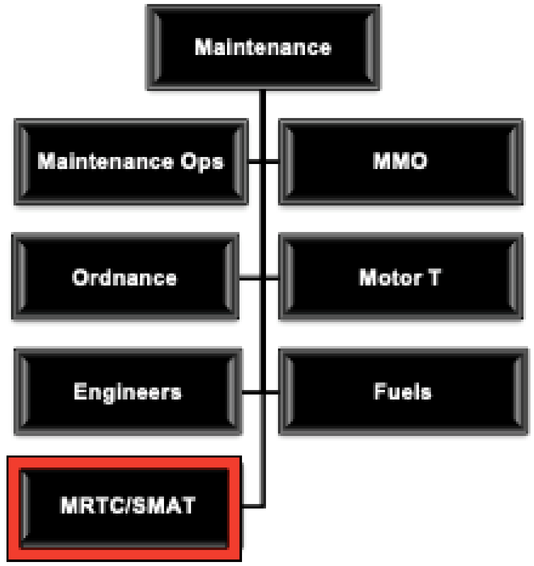
In 2018, the SMAT inspection program was replaced by the Preferred Sourcing Unit (PSU) inspection program (SMAT, interview with author, January 22, 2020). The intention of the program was to prioritize deployable MARFORRES units, who were assigned to support the execution of the Operational Plan for Southeast Asia and ensure compliance with current Marine Corps Orders and policies. It intended to identify any noncompliance in accountability and unit readiness. These units were especially required to correct deficiencies in a timely manner to ensure they were ready to mobilize when given the order (SMAT, interview with author, January 22, 2020). This program was in effect until 2019, when it was replaced by the re-establishment of the SMAT inspection program.

E. RE-ESTABLISHMENT OF THE SMAT INSPECTION PROGRAM

The re-establishment of the SMAT program intended to return to conducting triennial inspections for all MARFORRES account holders (those headquarter units who were property book owners). The program offers two forms of analysis: formal inspections and site assist visits (G. Hudson, personal communication, January 21, 2020). Formal analysis involves a thorough analysis of a unit's Supply and Maintenance sections, their processes and procedures, accountability, and record keeping. This analysis results in a formal report of any deficiencies found and corrective recommendations. The report is forwarded to the I-I OIC, AC/S G-4, and to the unit's MSC. The unit is then required to provide a corrective action plan, establishing acknowledgement of deficiencies and how they will become compliant (G. Hudson, personal communication, January 21, 2020). SMATs mentor and train Marines of inspected units on efficient and effective procedures to maintain and sustain compliance. The second form of analysis, site assist visits, is an informal inspection meant to train, mentor, and guide requesting units (or MSCs) who seek support in ensuring compliance with MARFORRES and Marine Corps orders and policies. Formal reports are not produced unless the MSC has requested such. While no official force order has been established, SMAT's mission is based on developed priorities as dictated by MARFORRES G-4 (G. Hudson, personal communication, January 21, 2020).

F. ORGANIZATION OF SMAT

From approximately 2002 to 2017, SMAT fell under the Deputy, G-4. This provided them with direct reach back to leadership, informing the AC/S G-4 and staff with the latest condition of their units. In an attempt to maximize efficiency and effectiveness, SMAT was placed directly under the Operations and Planning Division (SMAT, interview with author, January 22, 2020). Between 2017 and 2018, a close examination of the placement of SMAT led to a second re-organization in which the section fell directly under the maintenance section to answer to the Maintenance Officer. This is where SMAT currently resides (see Figure 3).



This briefly depicts the placement of the Supply and Maintenance Analysis Team (SMAT) under the Maintenance Section of Marine Forces Reserve G-4.

Figure 3. Organization of MARFORRES G-4 Maintenance Section

G. SMAT COMPOSITION

If fully resourced, the organizational structure of the SMAT is as follows:

(1) SMAT Officer in Charge (OIC)

(1) SMAT Staff Noncommissioned Officer in Charge (SNCOIC)

(2) Dedicated analysis teams

Each dedicated SMAT formation includes:

(2) Supply Inspectors

(2) Maintenance Commodity Inspectors

(1) Maintenance Management Inspectors

Civilian and contractor personnel are added to the team as required by the G-4. Note that the G-4 may add additional personnel to support mission requirements (G. Hudson, personal communication, January 21, 2020).

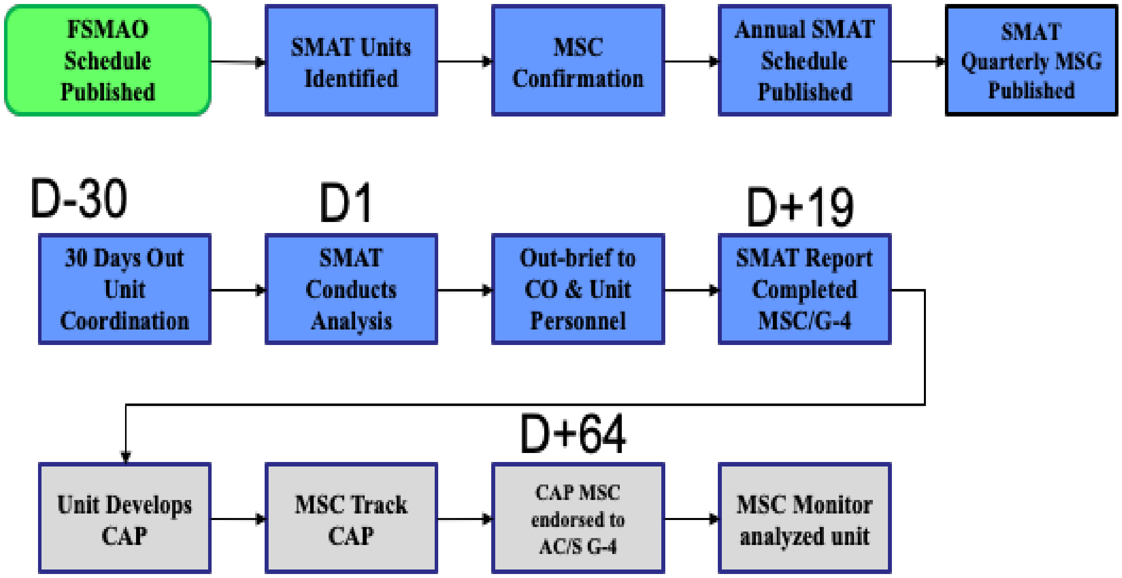
H. SELECTION CRITERIA FOR UNIT INSPECTIONS

Limited manpower and budgeting contribute to the number of units SMATs can inspect during a fiscal year (FY). Per interviews with MARFORRES G-4, FY 19 resulted in approximately twelve inspections. Currently, there is no set standard in choosing a unit for inspection. As of FY 19, units are identified for inspection based on FSMAO scheduling. SMATs inspect units within a year of its scheduled FSMAO to inform MARFORRES on the current readiness of the unit. This also provides SMAT with an opportunity to train and mentor Marines of the inspected unit on better practices and procedure to improve effectiveness and efficiency in Supply and Maintenance sections (SMAT, interview with author, January 22, 2020). These inspections provide units with an opportunity to improve processes and correct inaccurate records on their own.

Besides using FSMAO scheduling as a basis, SMAT uses other methods to select units for inspection. Within our current fiscal year (FY 20), SMAT inspections occur at the request of MSCs (SMAT, interview with author, January 22, 2020). While these are Site Assist Visits, the results of these inspection are reported directly to the MSC for action. Other methods include conducting Virtual SMAT analysis utilizing the Maintenance Management Tool (MMT) to determine which units show as “red-flags” (SMAT, interview with author, January 22, 2020). This tool takes as inputs Global Combat Support System - Marine Corps (GCSS-MC) records for that unit and provides outputs of accountability and readiness risk percentages. Those units who are deemed in the “red” (or mid to high risk for noncompliance) are chosen for ground inspection by SMAT. The MMT is very maintenance focused. There is very little supply data in the tool to which an analyst can gain useful insights (SMAT, interview with author, January 22, 2020). This may pose an issue for those units who receive a passing score during virtual analysis (and therefore, are not chosen for inspection), when in fact their Supply section is noncompliant. Currently, SMAT subject matter experts (SMEs) work under the assumption that if a unit’s Maintenance section is at risk, chances are the Supply section is at risk as well. This may not always be the case.

I. SMAT EXECUTION

When a unit is selected for SMAT inspection, SMAT SMEs conduct virtual analysis of the unit to determine its current condition. While all GCSS records are initially pulled, a pre-determined sample size of these records is actually analyzed (SMAT, interview with author, January 22, 2020). This is usually due to time constraints. In performing this pre-analysis, SMEs gain valuable insight into the current state of the unit while annotating possible discrepancies in procedure and noncompliance. SMEs provide units with 48- to 72-hour notice of those records chosen for ground inspection (SMAT, interview with author, January 22, 2020). This provides the unit with a small opportunity to gather all required records for presentation prior to inspection. Furthermore, this gives a unit a small window of time to identify issues prior to inspection, allowing for immediate corrections. The purpose of the inspection is about identifying noncompliance and rectifying them, then it is to fail a unit for inspection. Using this inspection technique, SMAT can place more focus on the mentorship and training aspect of the inspection. Per interviews with SMAT SMEs, units tend to be more forthcoming about their issues when the mindset focused more on aiding units in becoming compliant then exposing noncompliant units. See Figure 4 for an example of the SMAT execution process.



This chart depicts the execution process of the Supply and Maintenance Analysis Team (SMAT). SMAT, under one of its execution methods, based its unit inspections on FSMAO schedules. If a unit was scheduled to receive a FSMAO, SMAT scheduled said unit for inspection the year prior. As shown above, SMAT conducts numerous actions before, during and after executing an inspection. Before the inspection, a schedule is published via the Automated Message Handling System (AMHS) to inform units who have been selected for inspection. After the AMHS message had been published, the unit and SMAT conducted various coordination meetings to prepare for the upcoming analysis. Completion of the inspection led to follow on actions that included an out brief to the unit's CO and relevant personnel and a SMAT report to the Major Subordinate Command and to the G-4. The inspected unit required to report back with a corrective action plan (CAP) to which the Major Subordinate Command was required to monitor until its deficiencies were corrected. Follow-on inspections were not uncommon in extreme cases.

Figure 4. SMAT Execution Process. Source: G. Hudson, personal communication, January 21, 2020.

After a virtual inspection, the SMAT is ready to inspect the target unit. Upon arrival at the unit, SMAT members conduct an in-brief to explain the inspection plan of action, set expectations, and answer any questions the unit may have inspection (SMAT, interview with author, January 22, 2020). The execution of the inspection is broken down into two sections: Supply and Maintenance. In the Supply section, SMEs analyze seven fields having to do with requisition management. These fields include: Due and Status Files (DASF), property records, fiscal records, weapons accountability, Consolidated Memorandum Receipt (CMR), container management, and personal effects inspection (SMAT, interview with author, January 22, 2020). The Maintenance portion of the inspection is split into two facets: maintenance and maintenance management. Maintenance involves examining mission related inventory for its operational health and status, matching GCSS-MC records with physical reports, and accounting for Stock List-Level 3 (SL-3) (SMAT, interview with author, January 22, 2020). This includes operating select radios, or vehicles to examine its condition, or talking through process and procedures for maintaining said assets. Contrarily, Maintenance Management focuses on the examination maintenance record keeping, procurement, and disposal of assets.

Warehousing

1. Is a stock locator file maintained in such a manner to permit accurate location of supplies? (MCO 4400.201, Volume 3, Chapter 3, Paragraphs 030506.D and 030306; Volume 4, Chapter 3, Paragraph 0306(NEW REFERENCE FY-19)

2. Is property stored in a serviceable, ready for issue condition, and SL-3 complete? (MCO 4400.201, Volume 3, Chapter 2, Paragraph 021805.E and Chapter 3, Paragraph 030208)

3. Is the unit properly using individual Memorandum Records (IMR) for personnel signing-out Individual Combat Clothing and Equipment (ICCE)? (MCO 4400.201, Volume 3, Chapter 2, Paragraph 020507 and Volume 13, Chapter 6, Paragraph 0603)

4. Are effective check-in and check-out procedures/controls in place to manage the addition and removal of system access as users are joined and detached from the organization? (OMB A-123, Appendix A; CMC MSG 141835Z Nov 14)

5. Is the unit recovering Individual Combat Clothing and Equipment (ICCE)? (MCO 4400.201, Volume 3, Chapter 1, Paragraphs 010703, 020601, and 020602 and Chapter 4, Paragraph 042202)

6. Is the unit conducting monthly reconciliations between Individual Memorandum Records and the unit Alpha Roster? (MCO 4400.201, Volume 3, Chapter 2, Paragraph 020507 and Volume 13, Chapter 6, Paragraph 0603)

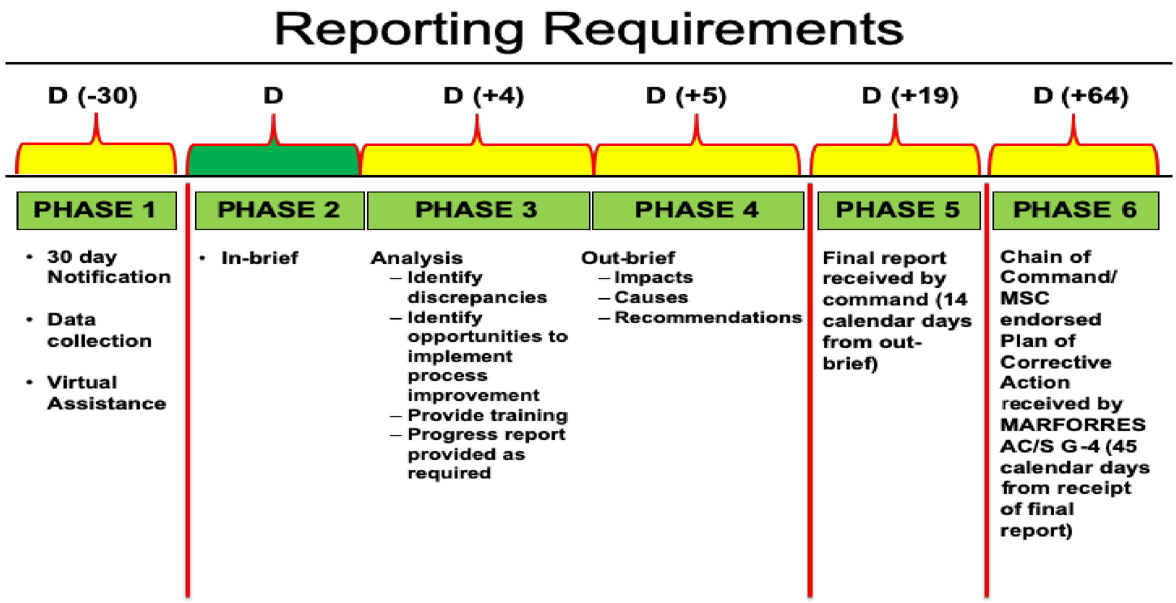
7. Does the warehouse planograph have a dedicated area for unserviceable Individual Combat Clothing and Equipment?(MCO 4400.201, Volume 3, Chapter 2, Paragraph 020507 and Volume 13, Chapter 6, Paragraph 0603)

8. Is the correct location numbering system being utilized? MCO 4400.201 Volume 3, Chapter 3, Paragraphs 030306; MFR MSG 101658Z Feb 15) (email traffic submitted to MFR Supply Chief for update of message (21 Aug 2018).

The figure above provides an example of the Supply Commodity Section Warehousing SMAT checklist. Take note of the fashion in which the checklist is formed. Instead of using terminology that stated compliance, or noncompliance with an item, the Supply and Maintenance Analysis Team (SMAT) used yes-or-no closed questions. This encouraged units to be more forthcoming with their deficiencies by using language that did not carry negative connotations such as being noncompliant with an order.

Figure 5. Example SMAT Checklist. Source: Supply and Maintenance Analysis Team (2019).

While each SMAT inspector executes their mission uniquely, the team's concept of operations is the same. Each member sits with those Marines responsible for their section, and discuss processes and procedures utilized. This is prior to looking at any items on the inspector's checklist. This provides the team with an opportunity to train and mentor before identifying noncompliance (SMAT, interview with author, January 22, 2020). After discussing processes and procedures, SMAT begins a close examination of records. Due to the large amounts of records and time constraints, members typically select a pre-determined sample size to analyze (G. Hudson, personal communication, January 21, 2020). This examination is conducted utilizing a SMAT checklist. The SMAT checklist is a mix of FSMAO and MARFORRES-specific compliance questions. Figure 5 provides an example version of the checklist. Observe that each question is in "Yes" or "No" format instead of compliance, or noncompliance. This is done intentionally to encourage the inspecting units to be more transparent about their issues (SMAT, interview with author, January 22, 2020).



This depicts the reporting requirements during a typical Supply and Maintenance Analysis Team (SMAT) inspection. Thirty days prior to inspection, SMAT conducts a virtual analysis of the inspected unit in preparation for the upcoming inspection. The unit is then notified of those targeted items SMAT is interested inspecting. This provides units with an opportunity to organize themselves appropriately in preparation for SMAT's arrival. During Phase 2–4, SMAT conducts an in-brief with unit leadership, conducts the inspection, and conducts an out brief addressing impacts, concerns, and recommendations. The unit will provide a corrective action plan (CAP) fourteen calendar days from the inspection in Phase 5, followed by an endorsement of the CAP by the Major Subordinate Command, which is sent to Marine Forces Reserve G-4 leadership in Phase 6.

Figure 6. Reporting Requirements for SMAT Inspection. Source: J. Rodriquez, personal communication, January 21, 2020.

At the end of an inspection SMAT inspectors compile their findings and conduct an out-brief with the unit's leadership and staff to include the I-I OIC, Commanding Officer, Supply and Maintenance Officers, and Supply and Maintenance Chiefs (see Figure 6) (SMAT, interview with author, January 22, 2020). The team briefs their top three "good" findings (what the unit is doing well), top three noncompliant findings, recommendations to rectify any issues, and answers to any questions. The team has approximately 30 days to provide a finalized report with all findings (approved by the Technical Analyst Chief and the Maintenance Officer) to the I-I OIC, Commanding Officer, AC/S G-4 and the unit's MSC. The unit owes an acknowledgement of receipt of the report, must establish a corrective action plan (provided to the MSC and AC/S G-4), and a time estimate for when they plan on being complaint. In a few cases, SMAT may re-inspect a unit to ensure a unit is compliant post-corrective action plan execution (SMAT, interview with author, January 22, 2020).

J. SCOPE OF THE PROBLEM

Within the last seventeen years, MARFORRES G-4 has seen several variations of the SMAT inspection program in the hopes of optimizing its resources to better execute its mandate to perform internal inspections. The current construct is not operating up to the expectation of G-4 leadership and quite frankly, the SMAT SMEs (SMAT, interview with author, January 22, 2020). Two themes arise in our examination of the SMAT inspection program that are attributing factors to its current state.

The first theme is the unclear delineation of SMAT from FSMAO. To the spectator, both teams provide the same function. Closer examination reveals that they do not. HQMC mandates MARFORRES to conduct internal inspections of its units, separate from FSMAO. The intent is to ensure these reserve units are aligned to, not only Marine Corps orders, policies, and procedures, but also to address those MARFORRES-specific orders, policies and procedures, which identify circumstances unique to the reserves (e.g., mobilization of a reserve unit in support of OPLAN execution) (SMAT, interview with author, January 22, 2020).

There are clear differences between SMAT and FSMAO. FSMAO acts as direct field representatives for the Commandant of the Marine Corps (CMC) and Deputy Commandant for Installations and Logistics (Field Supply and Maintenance Analysis Office [FSMAO], 2013). They conduct CMC-directed inspections and analysis aimed at determining current unit readiness and accountability throughout the Marine Corps (which includes MARFORRES). With dedicated offices on the East Coast, West Coast, and Western Pacific, FSMAO offices have dedicated teams to conduct thorough analysis anywhere there exists a Marine Corps unit. With shorter travel distance requirements coupled with dedicated manpower and budgets, FSMAO has the capability of inspecting units for 2–3 weeks, conducting in-depth analysis of every record within each of the commodity sections. Any inspection findings are briefed at the end of the inspection, and a determination of compliance or noncompliance is made. The finalized report is sent to the inspected unit as well as to the MSC and HQMC (SMAT, interview with author, January 22, 2020). Units are required to submit a corrective action plan with the expectation that all noncompliant items are rectified as expeditiously as possible. Contrarily, while SMAT is composed as reflected in Section G of this chapter, this is hardly reality. SMATs adapt to the mission at hand while being shaped by present manpower, budgetary, and timing constraints. Teams can vary from solely two members (be it, contractor or military) to a five-member team (SMAT, interview with author, January 22, 2020). A team is limited to inspecting a unit within a five-day period (SMAT, interview with author, January 22, 2020). This places restrictions on the depth of SMAT's analysis. Competing interests may cause SMATs to deviate from previously established schedules to re-inspect, execute training, or conduct quick-turn site assist visits. To counter this, SMATs have recently conducted Virtual SMAT Analysis to curb time and resource constraints; however, to limited avail. This typically limits inspections to approximately ten to twelve a year.

Further misconceptions arise when one compares the SMAT inspection program under MARFORRES to that within the active duty component. Within the active duty component, SMATs typically fall under FSMAO with its mission to conduct Site Assist Visits. Site Assist Visits are not inspections. The purpose of these visits is to mentor and train units in improving business practices. These visits must be requested by the unit and the result of the visit is an out brief of any findings. Typically, no report is compiled unless otherwise requested by the MSC. Since SMATs are located in vicinity of FSMAO offices, they have significantly shorter travel requirements. Contrarily, MARFORRES' SMAT Inspection program is tasked to execute formal scheduled inspections with secondary and tertiary mission sets that include Site Assist Visits (when requested and available) and Materiel Readiness Training Center (MRTC) courses, respectively (SMAT, interview with author, January 22, 2020). SMATs operational tempo requires flexibility and adaptability with limited resources to spread out through the course of a fiscal year. With 53 account holders, each with varying number of units spread throughout the United States, SMAT is required to travel long distances to inspect units with the understanding that they will not be able to examine every unit under each account (SMAT, interview with author, January 22, 2020).

The second theme, and what we address in our analysis, is the value and management of MARFORRES' limited resources. While we focus on the SMAT inspection program, this analysis is generalizable across MARFORRES G-4's other inspection programs. In understanding SMATs mission set alongside their flexible composition to fit inspection needs, and competing interests, it is clear that MARFORRES must conduct careful calculation and allocation of funds and personnel to support this requirement. Lack of intent and balance easily leaves units without examination, thereby keeping the AC/S G-4 (and the Commander of MARFORRES) uninformed about the accountability status, materiel readiness, and an accurate unit readiness sight picture. This leads to catastrophic consequences when it is time to mobilize. If resources are optimized according to particular budget, manpower, and time constraints, MARFORRES G-4 will gain a foothold on its inspection program (across all focus areas).

II. LITERATURE REVIEW

This chapter provides an overview of the underlying literature that supports our analysis. First, we will briefly discuss the various inspection programs that affect MARFORRES. Second, we will review linear programming with emphasis on integer linear programming to set the foundation for the optimization model used in our analysis. Third, we briefly discuss the ILOG® CPLEX optimizer, which is the principal solver used in our models. Fourth, the General Algebraic Modeling System (GAMS) will be introduced to build a sight picture on the optimization software used to solve our problem set. Finally, we briefly discuss the value-based modeling work conducted by Major Jun Xian Jeremy Yee to aid MARFORRES G-4 in understanding the value of its inspections, which informs our analysis.

A. BRIEF INTRODUCTION TO INSPECTION PROGRAMS AFFECTING MARINE CORPS FORCES RESERVE

In this section we will discuss the various inspections that MARFORRES must execute. Our intention is to introduce the various inspection programs that exist in MARFORRES' purview. Furthermore, its introduction informs the generalization of our model. A few of these inspection programs apply to the entire Marine Corps, while the remaining programs introduced here are MARFORRES-specific to address the unique nature of being a reserve. We have already introduced the SMAT inspection program (and will continue to focus on this program for the remainder of our analysis). The remaining four inspection programs discussed below are the following: Field Supply and Maintenance Analysis Office (FSMAO), Force Readiness Activation Assessment Program (FRAAP), Marine Crops Administrative Analysis Team (MCAAT), and the Command General Inspection (CGI) Program.

The Field Supply and Maintenance Analysis Office (FSMAO) conducts a Commandant of the Marine Corps-directed inspection aimed at ensuring its active and reserve units comply with Marine Corps orders and policies (FSMAO, 2013). During these inspections, dedicated FSMAO teams conduct detailed analysis of the supply and maintenance sections of targeted units to gain insight on the logistical welfare of these units. At the end of these inspections, the unit is given a grade indicating whether it met Marine Corps standards as compliant, or noncompliant (FSMAO, 2013).

The FRAAP is a reserve focused inspection program intended to evaluate a unit's activation readiness. In doing so, the unit is tested in its ability sustain force requirements in the deployment of forces in Phases 1 and 2 (Command Inspector General, n.d.). Moreover, inspectors assess the unit's ability to "activate, stage, and marshal personnel and equipment for follow-on movement prior to integration with a Gaining Force Commander (GFC)" (Command Inspector General, n.d.). This level of inspection is conducted by the MARFORRES Command Inspector General on an annual basis for those units identified as priority units by the G-3/5 and who fall into one of three categories: Global Force Management sourcing, units who have completed a Service Level Training Event, and units slotted for Operational Plan preferred sourcing (Command Inspector General, n.d.).

MCAAT analyzes how effective a unit's internal audit procedures, compliance with regulations, internal controls, system management, the conduct of administrative tasks at the command level, ability to execute disbursing and finance operations, and its ability to handle pay and entitlement transactions in the various systems that exist in the Marine Corps (e.g., the Marine Corps Total Force System, and the Defense Travel System) (Manpower and Reserve Affairs [M&RA], 2013). The resulting analysis informs various departments in the Marine Corps on the health of the unit's administrative business practices to include basic administration and Defense and Finance Operations. The informed departments include Headquarters Marine Corps, Manpower and Reserve Affairs, the Director, Manpower Information Systems, Program and Resources, Fiscal Division, and finally the Resources Finance Fiscal Branch (M&RA, 2013). While MCAATs are executed annually, only units identified and notified undergo the inspection during that fiscal year.

The CGI is an approximately three-day long inspection that involves assessing a unit's readiness across various functional areas. These include, but are not limited to evaluating unit-led programs (Sexual Assault and Prevention Response, Equal Opportunity, etc.), personnel readiness and inspections, the conduct of unit-led events such as the Combat Fitness Test and the Physical Fitness Test, unit reporting, Chemical, Biological, Radiation and Nuclear business practices, and general military knowledge and processes (such as unit managed policies and the request mast process). The inspection results in a report that is sent to the Force, Headquarters Group Commander of MARFORRES, while the inspected unit is required to provide an endorsed corrective action plan detailing how and when they plan to correct any deficiencies (Commanding General, Force Headquarters Group, 2016).

B. LINEAR PROGRAMMING MODELS

Linear programming involves maximizing, or minimizing, an objective function subject to linear constraints on a set of decision variables (Bradley, 1977). In practical application, this optimization technique is commonly used to solve a multitude of real-world problem sets to include (but not limited to) profit maximization, cost minimization, or resource allocation (e.g., the common transportation problem). Linear constraints take the form of an equality, or inequality with its associated decision variables having the capability of being unrestricted in sign (Bradley, 1977). The representation of the linear program in its standard form is as follows:

$$Max\ z = \vec{c}^T \vec{x}$$

subject to:

$$A\vec{x} \leq \vec{b}$$

$$\vec{x} \geq 0$$

where $\vec{c}^T$ is a transposed column vector of our objective function coefficients. $\vec{x}$ represents our decision variable of which takes the form of a column vector. A common example involves the minimization of costs, where our $\vec{c}^T$ takes on the form of cost coefficients for our $\vec{x}$ values (or decision variables), and $\vec{x}$ represents product quantity. Linear constraints take on the form $A\vec{x} \leq \vec{b}$, where A is an m x n matrix and $\vec{b}$ is the resulting column vector formed by the product between the A matrix and our decision variables, $\vec{x}$. The last constraint places a restriction on the decision variable as nonnegative. While this is standard form, this last constraint is not strict (as we will soon discuss). These linear constraints, together, form the feasible region in which the feasible solution may be found (Bradley, 1977). If feasible, that is all constraints are satisfied, the linear program will solve optimally at the extreme points of the feasible space. A common approach to solving linear programs is utilizing the simplex method. Developed by George B. Dantzig in 1947, the simplex method utilizes the canonical form of a linear program, where all constraints are equations and its decision variables nonnegative (as follows).

$$Max\ z = \vec{c}^T \vec{x}$$

subject to:

$$A\vec{x} = \vec{b}$$

$$\vec{x} \geq 0$$

Furthermore, all constraints but nonnegativity must be in the form of equalities, where the coefficients on the right-hand side are also nonnegative (Bradley, 1977). Constraints that are less than, or equal to some value, require the addition of slack variables, where the slack variable is nonnegative in nature. Contrarily, if the constraint is greater than, or equal to some value, we are required to add surplus variable. This surplus variable is nonnegative in nature. The vector of both basic and non-basic variables is known as a basic solution, and through an iterative process we set our non-basic variables to zero and solve for our basic variables. Furthermore, an optimal solution, if one exists, is found at an extreme point of the feasible region as defined by the constraints. In theory, if the feasible region is not empty and the problem is not unbounded, we can travel along the feasible space and find the maximum (or minimum) value at an extreme point of said region (Rardin, 2017).

However, we must take a different approach when our decision variables are integer. That is, our optimization takes the form of:

$$Max \sum_{j=1}^{n} c_j x_j,$$

subject to:

$$\sum_{j=1}^{n} a_{ij} x_j = b_i \quad \forall i = 1,2,\dots,m$$

$$x_j \geq 0 \qquad \forall j = 1,2,\dots,n$$

$$x_j \ integer \ \forall \ j = 1,2,\dots,n$$

The above mathematical programming model becomes what is known as an integer linear program (Bradley, 1977). This is the underlying premise of our optimization models. These decision variables may take the form of pure integer, or mixed integer, whereby some values of x can be real and some must be integer. A common example involves maximizing profit by considering investment options available to an investor, or business owner. That is, the objective is to "maximize total contribution from all investments without exceeding the limited availability of any resource." Other examples, applicable to the military, involve the standard scheduling problem (allocation of aviation assets to bases according to available resources), the warehousing problem (strategically storing logistical resource in advanced bases in support of operational plans [OPLAN]), or the transportation problem (assigning disposal sites based on munition tonnage from particular cache sites). A common method to solve an integer linear program is partitioning the feasible region into sub-divisions and determining the lower and upper bounds of each division until the optimal solution is reached (if the problem is feasible) (Bradley, 1977). This is known as branch and bound. Typically, in the form of an enumeration tree, the feasible region is continuously split until, in the case of a maximization problem, the lower bound is the highest integer feasible value found, whereas the upper bond is derived from a linear programming relaxation.

C. RELEVANT LINEAR PROGRAMMING MODEL

To gain further insight in the application of linear programming, we conduct a brief discussion of Major Emily LaCaille's thesis, "Optimizing Global Force Management for Special Operations Forces" (LaCaille, 2016). In context, the United States Special Operations Command (USSOCOM) required a planning tool that met force requirements of those missions of highest priority while simultaneously considering current SOF capabilities. Prior to her thesis, USSOCOM met its allocation requirements by conducting various meetings throughout the year to choose and rank those mission sets they were going to execute. To solve this problem, LaCaille introduced a multi-period inventory model that maximized mission priority, thereby optimizing the allocation of units to those mission sets subject to unit availability constraints. As a result, LaCaille informed USSOCOM on their current resource limitations that affect mission fulfillment, arming USSOCOM leadership with information that allowed for effective decision making on future resource allocation actions.

D. CPLEX

Created by IBM, CPLEX, or formally known as the ILOG CPLEX optimizer is a tool utilized to solve linear programs (to include network flow problems), mixed integer programs, and quadratic programs (IBM Developer Answers [IBM], 2016). There are three components of the associated software: Interactive Optimizer, Concert Technology, and the Callable Library. The Interactive Optimizer is a program in the form of an executable, usable on both Windows and UNIX-based platforms, takes as inputs either interactive data or files containing the problem set, solves the intended problem, and provides a solution either interactively, or in the form a text file (IBM, 2016). The Concert Technology uses C++, Java, or .NET class libraries that allows users to utilize an Application Programming Interface (API) to embed the CPLEX solver into their programs. See Table 1 for an example of the Concert Technology Library offered by CPLEX.

Table 1. Concert Technology Libraries. Source: IBM (2016).

Table 1. Concert Technology libraries

	Microsoft Windows	**UNIX**
C++	`ilocplex.lib concert.lib`	`libilocplex.a libconcert.a`
Java	`cplex.jar`	`cplex.jar`
.NET	`ILOG.CPLEX.dll` `ILOG.Concert.dll`	

This is a single example of the concert technology libraries provided by IBM's ILOG CPLEX Optimizer.

The Callable Library, to which the Concert Technology takes advantage of, is a C library that allows its users to embed CPLEX into their programs on both Windows and UNIX-based platforms (IBM, 2016). Similarly, the Python API and CPLEX connector for Matrix Laboratory (MATLAB) provide interfacing capability that allow programmers to access the CPLEX callable library and technology. Most importantly, CPLEX's underlying solver method employs the SIMPLEX technique if the problem involves a linear program, and Branch and Bound (through the interactive optimizer) if the program is integer in nature. Our analysis uses the CPLEX solver to solve the underlying optimization model.

E. GENERAL ALGEBRAIC MODELING SYSTEM

The General Algebraic Modeling System (GAMS) is an optimization language software that allows its user to form and solve models of interest. Although the modeler will be required to learn how to write in GAMS language, the software keeps the required code relatively simple for its user to understand and implement (GAMS, 2020). Moreover, the software has access to a plethora of algorithms to solve the user's desired mathematical program, thereby allowing its user to focus on formulation and implementation rather than the solving method. We use GAMS with a CPLEX solver to solve the associated integer linear program that is the basis of the optimization model. In addition, while GAMS offers an interactive application interface, the user can exploit the GAMS/Python API to solve models using the Python Programming Language and software. This has provided users with extended capabilities to use the latest of computing and programming technology. See Figure 7 for an example of GAMS language.

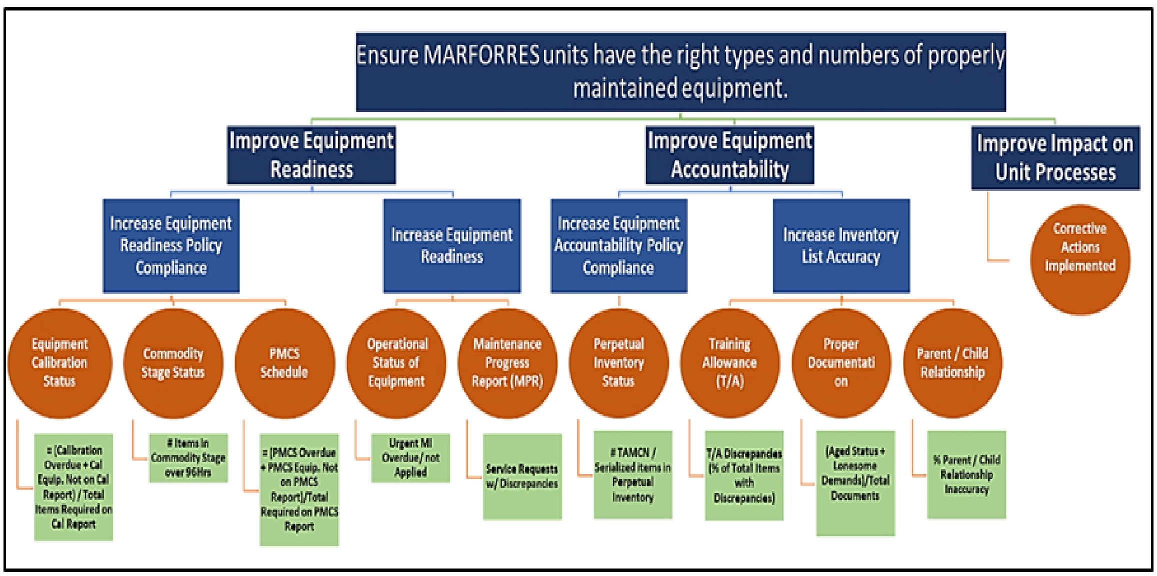
```
*------Objective function------------------------------------------
OBJ..      Z
           =E=

           SUM((u,t)$UT(u,t),pri(u,t) * Y(u,t)) - muPen*SUM((u,t)$MT(u,t),MU(u,t))
           ;


*------ Constraints------------------------------------------


c1(t,c)..
                          SUM(u$UT(u,t),fteReq(u,c)*Y(u,t))
                          =L=
                          fteAvail(t,c)
                          ;

c2(u)..
                          SUM(t$UT(u,t),Y(u,t))
                          =L=
                          1
                          ;

c3(u,up,t)$(MT(u,t) AND ST(up,t) AND FAR(u,up))..
                          Y(u,t) + Y(up,t)
                          =L=
                          1
                          ;


c4(u)$M(u)..
                         SUM(t$MT(u,t),Y(u,t))
                         =e=
                         1 - sum(t$MT(u,t),MU(u,t))
                          ;


**************** Solve ****************************************

MODEL SMAT  /OBJ,c1,c2,c3,c4/;

SOLVE SMAT USING MIP MAXIMIZING Z;

display Y.l, Mu.l
;
```

This is a brief depiction of the optimization model utilized in this thesis as an example of the structure of the syntax and language of the GAMS software.

Figure 7. Example of GAMS Language Structure

F. VALUE-BASED MODELING

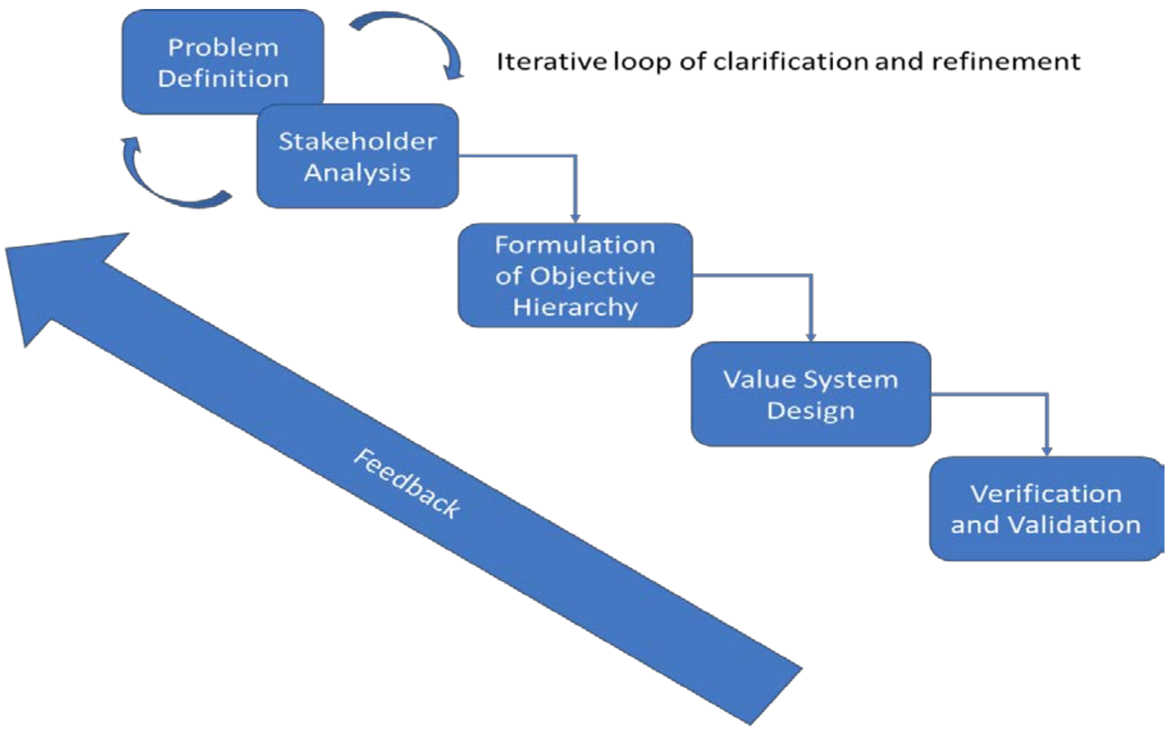
As part of an ongoing study that informs our analysis, led by Dr. Alejandro Hernandez of the System Engineering Department at the Naval Postgraduate School, Master's student Major Jun Xian Jeremy Yee of the Singapore Armed Forces develops measurable system attributes and value models to aid MARFORRES G-4 in better understanding the significance of the SMAT inspection program (Yee, 2019). The model develops a stakeholder-derived objective hierarchy (see Figure 8) which provided supply and maintenance ratings for each associated attribute (Yee, 2019). Major Yee hypothesizes that there were three main relationships in which attributes took shape: linear, concave, or S-shaped. Those supply rating attributes which contained a correlation of 0.5 or more were classified as linear and their values derived (Yee, 2019). Those ratings found to have little correlation, on the other hand, required shape determinations based on "operational implications and theoretical concepts." As Major Yee explained, " a concave value model is premised on the law of diminishing returns, in which the value derived from the inspection diminishes with every additional inspection finding uncovered" (p. xvi).



The depicts the objective hierarchy established by Maj Yee in his value-based modeling efforts (Yee, 2019). At the top of the hierarchy, Maj Yee recommends that Marine Forces Reserve ensure its units have properly maintained equipment. This is further broken down into three sections: improve equipment readiness, improve equipment accountability, and improve impact on unit processes. Under these sections are requirements that Marine Forces Reserve must fulfill to ensure success of its intended mission in conducting Supply and Maintenance Analysis Team (SMAT) inspections.

Figure 8. SMAT Inspection Objectives Hierarchy. Source: Yee (2019).

Major Yee uses the International Council on Systems Engineering (INCOSE) Handbook to determine measures of effectiveness for operational objectives intended for the operational environment (see Figure 9). Furthermore, he examines operational factors to develop the value of the SMAT inspection program to MARFORRES' mission. Most importantly, he provided MARFORRES leadership with the capability to develop and refine their own objectives and measures based on operational analysis that places the stakeholder at the forefront of the process, using the Waterfall method as its foundation (Yee, 2019).



This displays the nature of the Waterfall Process as utilized by Major Yee in his value-based model (Yee, 2019). As in its system engineering form, the analyst is required to define the problem and conduct stakeholder analysis iteratively. Once complete, the analyst formulates an objective hierarchy which leads to value system design. Upon returning a sound design, the analyst must verify and validate the model to ensure it correctness and accuracy. The process is in feedback loop that allows for continuous updating and changes as required.

Figure 9. Waterfall Process Model for Value System Development. Source: Yee (2019).

As a result, Major Yee came to two main results: the successful development of a value function, and the development of a communication tool (Yee, 2019). The value function developed "relevant, defendable, traceable, and repeatable means" to articulate measures to evaluate MARFORRES G-4's SMAT inspection program (Yee, 2019). The function is as follows:

$$u(x_1, \dots, x_n) = \sum_{i=1}^{N} k_i v_i(x_i)$$

The resulting communication tool allows SMATs to use specific metrics to collect quantifiable and qualitive data regarding executed inspections to in turn inform MARFORRES' mission while aligning MSCs to said mission. Additionally, these attributes aid in communicating the relevance and importance of the SMAT inspection program to MARFORRES (Yee, 2019). With these conclusions, SMAT can theoretically create an accurate sight picture of the current operational capabilities of its SMAT inspections, opening opportunities to developing quantifiable, and defendable metrics to analyze the value of each inspection. Therefore, with Major Yee's findings and our analysis, SMAT gains better insight on the value of its inspection program, while accurately evaluating its associated inspection cycle.

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III. MODEL FORMULATION

A. MULTI-PERIOD OPTIMIZATION MODEL

This chapter begins with the assumptions, limitations, and restrictions associated with our analysis. We then discuss the development of MARFORRES unit prioritization criteria and its relevance to the objective function. We close this chapter with a discussion on model formulation.

1. Assumptions

SMAT scheduling periods are represented as consecutive quarters. Each unit is given a target quarter for inspection. We assume if a unit is not inspected in its target quarter, it can be inspected up to two quarters prior. This provides the model with flexibility by relaxing the target inspection quarter.

Our analysis uses data instances from SMAT inspection program data. A SMAT inspection is a five-day process that involves investigating target commodity sections (Supply, Communications, Motor Transport, Ordnance, Maintenance, Bulk Fuel, Engineers, and Weapons). The associated resource to inspect a unit is defined as a *Full Time Equivalent (FTE)*, which equates to one inspector working five business days at an inspected unit.

FTE resource availability is represented differently in each model. In MILP(1A), we assume MARFORRES is restricted in manpower due to the limited availability of its SMAT inspectors throughout the year. We set a $manpowerbudget_t$ based on the number of inspectors available and the allowed number of inspections an inspector participates in per quarter. MILP(1B) addresses availability at the commodity section level. Each commodity is assigned total available resource per quarter.

Based on SMAT policy, we breakdown potential units for inspection into two groups: major units, or subordinate units. For the SMAT data instance that we focus on in Chapter IV, we assume a major unit is a Mechanized Allowance List (MAL), or property book holding unit. This applies to a majority of the headquarter units in the data provided.

We further assume all major units must be inspected. On the other hand, subordinate units are those units that do not fall under MAL and property book holding units. We are not required to inspect all subordinate units.

SMATs will not inspect subordinate units farther than 200 miles from a major unit during an inspection period. We ensure every subordinate unit selected is within a 200-miles of every major unit selected in the same time period.

In the introduction, we discuss SMAT execution and the possibility of conducting re-inspections for select units requiring it. For the purpose of this model we do not address re-inspections. We assume that SMAT will only inspect each unit once in a three-year period.

2. Limitations and Restrictions

We are limited to the data provided by MARFORRES G-4, which focuses on the SMAT inspection program and tends to discount the operational aspects that may be important in other inspection contexts. Although this data lacks costs for each inspection and clear resolution on inspector-to-commodity section relationships, we use SMAT's current policy, subject matter expertise, and additional insights received from MAFORRES Staff to inform our analysis and to fill gaps in our SMAT inspection program data.

Prioritization of units is determined from interviews with MARFORRES G-4 Staff. They are ranked based on operational tempo, mobilization based on operational plans (unclassified), MAL and property book holding units, and targeted scheduling periods. Furthermore, reward values are assigned to units based on their prioritization and appointed inspection periods. These values are tested for robustness to ensure consistency in the model and are captured as the objective function coefficient, $Pri_{u,t}$. We show how inspection values are determined in Chapter IV.

B. FORMULATION

We introduce two multi-period mixed-integer linear programming models, each of which seeks to maximize the total value of units selected for inspection. The first mixed-integer linear program, MILP(1A), shows the effects of manpower restrictions on unit selection. MILP(1B) is used to analyze how resource availability affects the problem.

1. Mixed-Integer Linear Program 1A Formulation, MILP(1A)

a. *Sets and Indices*

$t \in T$	Time period {Quarter 1,…,Quarter 14}
$u,u' \in U$	Unit Identification Code (UIC)
$c \in C$	Commodity Section {Supply, Communications, Motor Transport, Ordnance, Maintenance, Bulk Fuel, Engineer, Weapons}
$u \in M$	Major unit u
$(u,t) \in UT$	Unit u can be inspected in period t
$(u,t) \in MT$	Major unit u can be inspected in period t
$(u,t) \in ST$	Subordinate unit u can be inspected in period t
$(u,u') \in FAR$	Unit u is at least 200 miles from unit u'

b. *Parameters*

$fteReq_{u,c}$	Labor requirement for unit u and commodity c [FTE]
$Pri_{u,t}$	Reward for inspecting unit u during period t
$muPen$	Penalty associated with not inspecting a major unit
$manpowerBudget_t$	Amount of manpower allowed during period t

c. *Binary Variables*

$Y_{u,t}$	=1 if unit u is inspected in period t, 0 otherwise

d. *Continuous Variables*

MU_u	=1 if unit u is never inspected in any period t, 0 otherwise

e. *Formulation*

$$MAX\ \sum_{(u,t)\in UT} Pri_{u,t}Y_{u,t} - muPen\sum_{u\in M} MU_u$$

subject to:

$$\sum_{u:(u,t)\in UT}\sum_{c\epsilon C} fteReq_{u,c}Y_{u,t} \le manpowerBudget_t \qquad \forall t \in T \qquad \text{(C1a)}$$

$$\sum_{t:(u,t)\in UT} Y_{u,t} \le 1 \qquad \forall u \in U \qquad (C2)$$

$$Y_{u,t} + Y_{u',t} \le 1 \qquad \forall (u,u') \in FAR, t \in T: (u,t) \in MT, (u',t) \in ST \qquad \text{(C3)}$$

$$MU_u = 1 - \sum_{t:(u,t)\in MT} Y_{u,t} \qquad \forall u \in M \qquad \text{(C4)}$$

$$Y_{u,t} \in \{0,1\} \qquad \forall (u,t) \in UT \qquad \text{(C5)}$$

$$MU_u \ge 0 \qquad \forall u \in U \qquad \text{(C6)}$$

C. DISCUSSION

1. Objective Function

The objective function maximizes total inspection value for inspecting units. The binary variable, $Y_{u,t}$, takes on a value of 1 for units that are chosen for inspection, and 0 for those not inspected. Finally, the second portion of the objective function extracts a large penalty, *muPen*, from the total reward value for each major unit that is not inspected.

2. Constraints

Constraint (C1a) ensures there is enough manpower to support inspections based on total FTE requirement. We call this a $manpowerBudget_t$. Constraint (C2) ensures that each unit is inspected at most once. Constraint (C3) ensures that every subordinate unit selected for inspection for a given quarter is within 200 miles of every major unit selected during the same quarter. We call these inspection clusters. Constraint (C4) ensures that every major unit is inspected once. The continuous variable, MU_u records when major units are not inspected in any time period. If a major unit is not selected, we extract a large penalty from the total inspection value in the objective function. This enforces the requirement to select all major units, while informing us when this is not possible and which units are affected. Constraints (C5) and (C6) define decision variable domains.

A typical instance of MILP(1A) defines approximately 740 decision variables, of which approximately 700 are binary, and 6,100 constraints. When implemented in GAMS 28.2.0 and solved with CPLEX 12.9.0.0, such an instance solves in approximately five minutes using a 1.10 GHz Dual-Core Intel Core i3 with 8 GB RAM (GAMS, 2020).

D. MIXED LINEAR PROGRAM 1B FORMULATION, MILP(1B)

MILP(1B) analyzes the affects resource availability has on unit selection by targeting commodity sections per quarter. We modify MILP(1A) by replacing constraint (C1a) with the following:

$$\sum_{u:(u,t)\in UT} fteReq_{u,c} Y_{u,t} \leq fteAvail_{t,c} \qquad \forall t,c \qquad (C1b)$$

Constraint (C1b) ensures that the required FTEs for a unit's inspection ($fteReq_{u,c}$) are available from SMAT ($fteAvail_{t,c}$). All other constraints remain the same.

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IV. DATA, RESULTS, AND ANALYSES

This chapter reviews the data, results, and analysis as it pertains to the two main cases we investigate in this study: a look into SMAT's current policy and deviating from SMAT policy. These two cases provide us with perspective to fully understand SMAT inspection value and its byproducts, e.g., inspection coverage. We start our discussion by introducing the SMAT inspection program data framework as it applies to all cases we investigate. This is followed by a study of SMAT's current policy, any specific data instances related to this investigation, a review of our results, and the corresponding analysis. We then discuss deviation from SMAT policy, its specific data instances, and the results that follow. We conclude with a brief discussion on model generalization as it pertains to other inspection programs within MARFORRES' purview.

A. SMAT INSPECTION PROGRAM DATA FRAMEWORK

The SMAT data instance we analyze is retrieved from MARFORRES G-4's SMAT inspection program. Each row within the dataset is an activated reserve unit belonging to MARFORRES. In total, there are 509 activated units, each with identifying information such as Unit Identification Codes (UIC), Activity Address Codes (AAC), latitude and longitudinal data (in decimal degrees), inspection prioritization, and FTE requirements for relevant commodity sections. We address units, U, by their assigned UIC as a unique identifier in this analysis. We remove 253 of the 509 units from this dataset due to unit de-activation, unit re-organization, or units not subject to SMAT inspection. Of the remaining 256 activated units, we remove 24 units with missing data points that could not be adjudicated by MARFORRES. Finally, we designate 45 of the remaining 232 units as major units M (those of which must be inspected) with the remaining 187 units designated as subordinate units. In this data instance, a unit, u, is designated as a major unit, M, if they are MAL, property book holding units, or Bulk Fuel units. We provide Table 2 as an example of the SMAT inspection program instance.

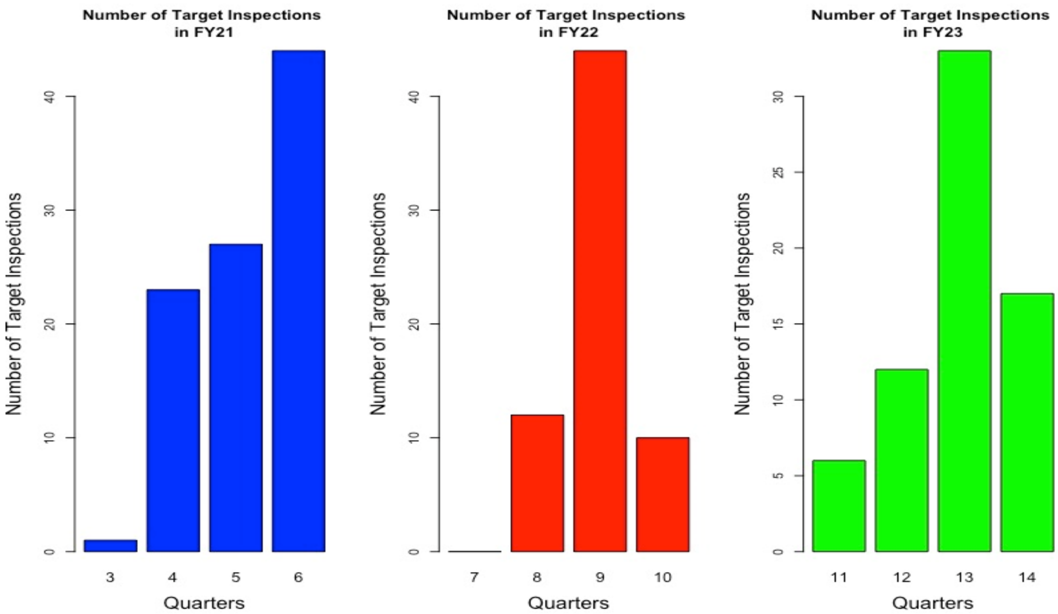
Table 2. Example SMAT Inspection Program Data

TFSMS UIC	Latitude	Longitude	Established Priority	Supply	Comm	Motor T	Ordnance	Maint Mgmnt	Bulk Fuel	Engineer	Heavy Weapons	FY21	FY22	FY23
M00242	32.749937	-97.330731	3	4	1	1	0.6	1	0	0.4	0			12
M00245	40.025998	-74.585866	2	4	1	0	0.6	1	0	0.4	0		9	
M00407	42.316236	-87.837948	1	2	1	1	0.6	1	0	1	0	6		
M00408	42.316236	-87.837948	1	2	1	0	0.4	0	0	0.4	0	6		

The table displays an example of SMAT inspection program data we use in this analysis. All data is provided by MARFORRES. The data is broken down by unit name, Unit identification Codes (UIC), location data, inspection priority, commodity section data in Full Time Equivalent (FTE) units, and target inspection periods (in quarters) represented by the last three columns.

We are also provided with target inspection periods spanning FYs 21 to 23. Target inspection periods are those quarters within each FY that MARFORRES intends on inspecting its units. Per SMAT policy, we allow a unit to be inspected at most two quarters prior to its target inspection quarter. These alternative inspection periods are known as out-quarter inspection periods and allow flexibility for units that cannot be inspected during their target inspection periods. Furthermore, we use the last two quarters of FY 20 to provide model flexibility. These two quarters are artificial in nature and they allow units with target inspection periods in quarters three and four to shift into out-quarter inspection periods. This data makes up the set *MT* and *ST* in both models.

We count quarters consecutively, starting from the last two quarters of FY 20. In other words, the end of FY 20 represents quarters 1 and 2, thereby making FYs 21, 22, and 23 quarters 3 to 14 (see Table 2 as an example). Figure 10 provides the distribution of target inspection periods per quarter. Quarters six, nine, and thirteen have the largest number of target inspections in their respective fiscal years.

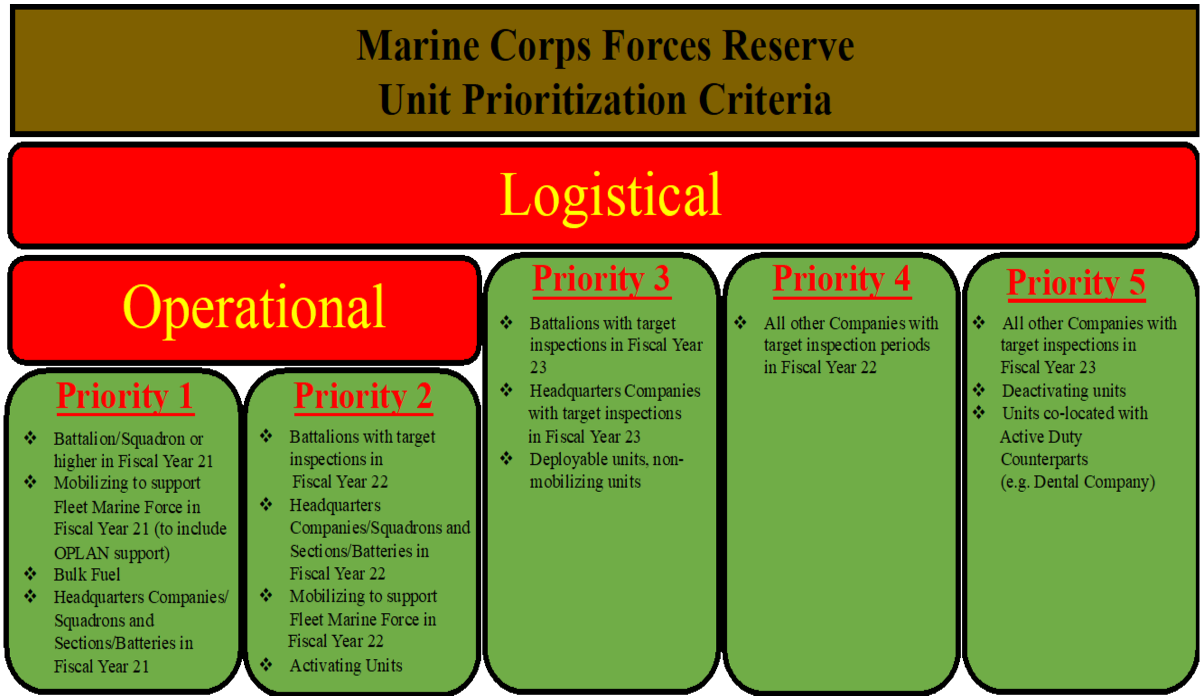


This displays the distribution of the target inspections per fiscal year. We can see a large number of units have target inspection periods in FY 21, followed by FY 23.

Figure 10. Distribution of Target Inspections Per Fiscal Year

1. MARFORRES Unit Prioritization Criteria

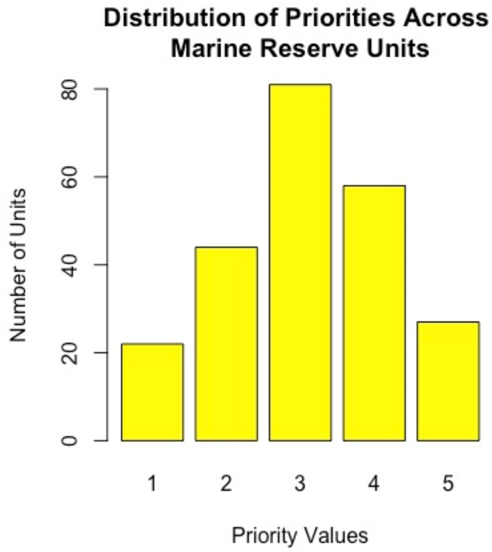
All units that are eligible for inspection are prioritized based on criteria, shown in Figure 11, that incorporate both the operational and logistical commitments as laid out in MARFORRES policy. Logistical attributes are requirements that align with MARFORRES-mandated priorities, such as inspecting those MAL and property book owning units. In considering operational commitments, we prioritize deployable and mobilizing reserve units, since these units are the primary focus of effort in augmenting the active duty Fleet Marine Force during Service-Level exercises, crisis response, and operational plan execution. Operationally related priority assignments are derived based on assumptions grounded on personal interviews with MARFORRES Staff and SMAT policy due to lack of data. Of all the commodity sections that MARFORRES inspects during a SMAT inspection, Bulk Fuel units are assigned the highest priority because of the large operational and logistical implications this commodity has on the success of Marine Corps mission sets.



The chart displays the MARFORRES unit prioritization criteria developed based on personal interviews with staff leadership at the G-4 and SMAT level. The above criteria are broken down into Operational and Logistical commitments to address the needs of the supported and supporting functions that exist in MARFORRES. As a majority of the data we retrieved is logistical in nature, we created attributes that focused on this fact. We further address operational commitments by making analytical assumptions based on limited SMAT data provided and personal interviews with MARFORRES Staff. A priority one unit is of the highest priority and is operationally heavy to reflect the end state in conducting these inspections; that is, units that will play a large role in augmentation and activation to support the active duty Fleet Marine Force. At the other end of the spectrum, a priority five unit are those other units that have either deactivated, are co-located with another unit, or of target inspections that are 3 or more years in the future.

Figure 11. Marine Corps Forces Reserve Unit Prioritization Criteria

Priority values range from one to five, where priority one units are the highest ranking and priority five units are the lowest. Figure 11 defines the assignment criteria we used to assign these priority values. As shown in Figure 12, a majority of our units fall into priority 3. Our distribution is slightly right-skewed, where a majority of the subordinate, non-mobilizing and non-deployable units reside. As expected, units that are near deployment or assigned mobilization to support the active duty force are the main target of inspections.



This depicts the distribution of priority values across units in the SMAT inspection program data.

Figure 12. Distribution of Inspection Priorities Across Units in SMAT Data

2. Objective Function Coefficient: Inspection Value Data

We establish inspection values based on assigned unit priorities. This data makes up $Pri_{u,t}$ of our objective function coefficient. In the development of these inspection values, several value ranges are tested and gauged for robustness and consistency. The values we use in this analysis are the least sensitive to change during these tests. A priority one unit is assigned an inspection value of 500. Consecutive priorities are assigned values half of the previous inspection value assignment. Inspection values for out-quarter inspection periods are discounted by half of its original inspection value per quarter per shift. For example, suppose Marine Air Support Squadron (MASS) 6's target inspection period is quarter four of FY 21. MARFORRES G-4 deems MASS-6 a priority two unit, and therefore, we assign the unit an inspection value ($Pri_{M00983,4}$) of 250. However, if quarter four is not available this leaves MASS-6 with two possible out-quarters for inspection, quarters three and two. For each of these quarters, MASS-6 receives inspection values of 125 ($Pri_{M00983,3}$) and 62.5($Pri_{M00983,2}$), respectively. See Table 3 for the range of inspection values that make up $Pri_{u,t}$ in our analysis and Table 4 for an example of $Pri_{u,t}$

data instances. Other methods to develop these inspection values should be investigated as possible future research.

Table 3. Inspection Value Assignment Data

Logistical Priority Value	Reward for Target Quarter	Reward for 1 Quarter Prior to Target	Reward for 2 Quarters Prior to Target
1	500	250	125
2	250	125	62.5
3	125	62.5	31.25
4	62.5	31.25	15.625
5	31.25	15.625	7.813

The table displays the inspection values, $Pri_{u,t}$, used in this analysis. An inspection value is assigned to each priority value which makes up the objective function coefficient data. Inspection values were tested for robustness to ensure consistency in the model.

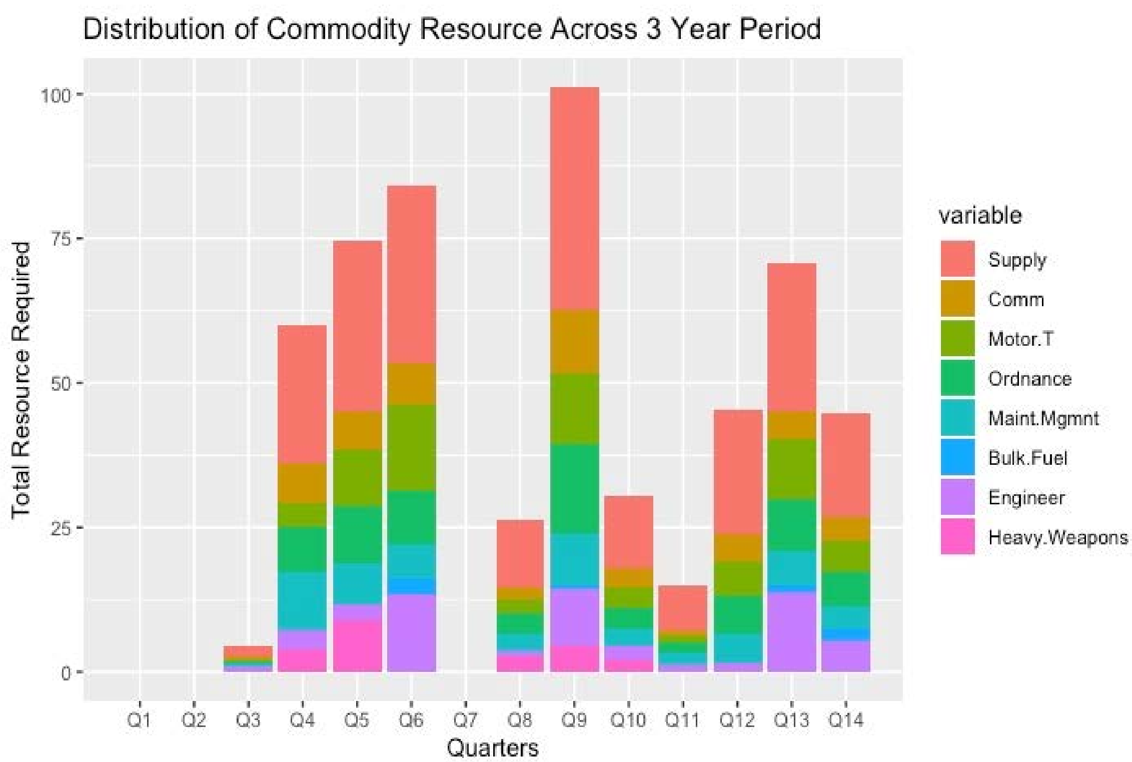
Table 4. Example of Inspection Value Assignments in SMAT Inspection Program Data

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14
M00242	0	0	0	0	0	0	0	0	0	15.625	31.25	62.5	0	0
M00245	0	0	0	0	0	0	15.625	31.25	62.5	0	0	0	0	0
M00407	0	0	0	31.25	62.5	125	0	0	0	0	0	0	0	0
M00408	0	0	0	62.5	125	250	0	0	0	0	0	0	0	0
M00409	0	0	0	125	250	500	0	0	0	0	0	0	0	0
M00510	0	0	0	0	0	0	0	0	0	0	15.625	31.25	62.5	0
M00524	0	0	0	0	0	0	0	0	0	0	0	15.625	31.25	62.5
M00526	0	0	0	0	0	0	0	0	0	0	0	15.625	31.25	62.5
M00527	0	0	0	0	0	0	0	0	0	0	0	15.625	31.25	62.5
M00541	0	0	0	0	0	0	0	0	0	0	15.625	31.25	62.5	0
M00542	0	0	0	0	0	0	0	0	0	0	0	15.625	31.25	62.5
M00544	0	0	0	0	0	0	0	0	0	0	15.625	31.25	62.5	0

This provides a brief example of inspection value assignment, $Pri_{u,t}$, in the SMAT data we use in our analysis. Inspection values shift according to a unit's target inspection period. For this analysis, we allow inspections to shift at most two quarters from their target inspection period.

3. Unit Resource Requirement (Full Time Equivalent Data)

Commodity section data are in the form of FTEs as shown in Table 2. One FTE is equivalent to one inspector working five business days (or 0.2 FTEs). The smallest FTE value we quantify is 0.1 FTEs. Figure 13 provides the distribution of total resources required, $fteReq_{u,c}$, to inspect units by quarter. Quarters associated with FY 20 provide the model with slack for borderline units in FY 21 and have no actual associated resource requirement. Of the three years we analyze, FY 21 requires the largest number of resources, because MARFORRES G-4 has more accurate data for the upcoming fiscal year than for the out-years, FYs 22 and 23. As a result, we expect the model to work harder in maximizing total inspection value for units selected in FY 21. Of the commodity sections, Supply requires the most resource, followed by Ordnance and Motor Transport. This plays a large role in how resource is distributed in MILP(1B).



This displays the distribution of resources required, $fteReq_{u,c}$, to inspect all units across commodity sections in their target inspection periods. These values are based on what is required to inspect each unit. Quarters one and two are artificial quarters and therefore have no assigned resource requirement. Finally, no unit is assigned quarter seven as a target inspection period. This quarter has no associated resource requirement.

Figure 13. Distribution of Commodity Resource Across a Three-Year Period

B. SMAT'S CURRENT POLICY

In this section, we introduce two cases wherein we analyze SMAT's current policy. The first analysis involves a look into the effects of a manpower budget on the maximization of total inspection value. The second portion of this section analyzes SMAT policy through the lens of varying total resource availability. This reflects the ever-changing availability of SMAT inspectors with commodity section expertise throughout our three-year period and its direct effect on total inspection value (and as a byproduct, inspection coverage).

1. Manpower Budget

To gain an understanding of how MARFORRES resource allocation affects inspection value ($Pri_{u,t}$), and coverage, we start by analyzing how the change in the number of inspectors ($manpowerBudget_t$) plays into the problem using MILP(1A). We call inspector availability MARFORRES' manpower budget. In conducting this analysis, we examine how MARFORRES' current policy is implemented and whether it is feasible given our data instance. Additionally, we provide a look into two instances where, as a result of maximizing total inspection value, we also expand on the total number of units selected. This will inform MARFORRES on how SMAT structure plays a direct role in maximizing total inspection value and, as a byproduct, can expand inspection coverage within target inspection periods.

a. Full Time Equivalent Data: Manpower Budget

We develop $manpowerBudget_t$ by taking the product between the maximum number of inspections an inspector participates in per quarter and the number of inspectors available, in units of FTEs. $manpowerBudget_t$ becomes the right-hand side of constraint (C1a). In this section, we analyze varying team sizes ranging from five to ten inspectors. We provide Table 5 as an example of the $manpowerBudget_t$ data instance we use in this analysis.

Table 5. Example of $manpowerBudget_t$ Data

Number of Inspectors	Number of Inspections Per Month	Number of Inspections Per Quarter	Manpower Budget (FTEs)
5	2	6	30
6	2	6	36
7	2	6	42
8	2	6	48
9	2	6	54
10	2	6	60

This table presents associated data for $manpowerBudget_t$ considering changes to the number of inspectors on SMAT.

b. Assumptions, Limitations, and Restrictions

Based on interviews with MARFORRES G-4 staff, an inspector can only conduct two inspections per month. There are three months in a quarter. With this information we assume that an inspector is limited to six inspections per quarter. In addition, we assume inspectors are homogenous in that any individual SMAT inspector can inspect any of the commodity sections within a unit, i.e., SMAT inspectors are not specialized and all have the same capabilities. Finally, the number of inspectors MARFORRES will use remains the same in our three-year time horizon.

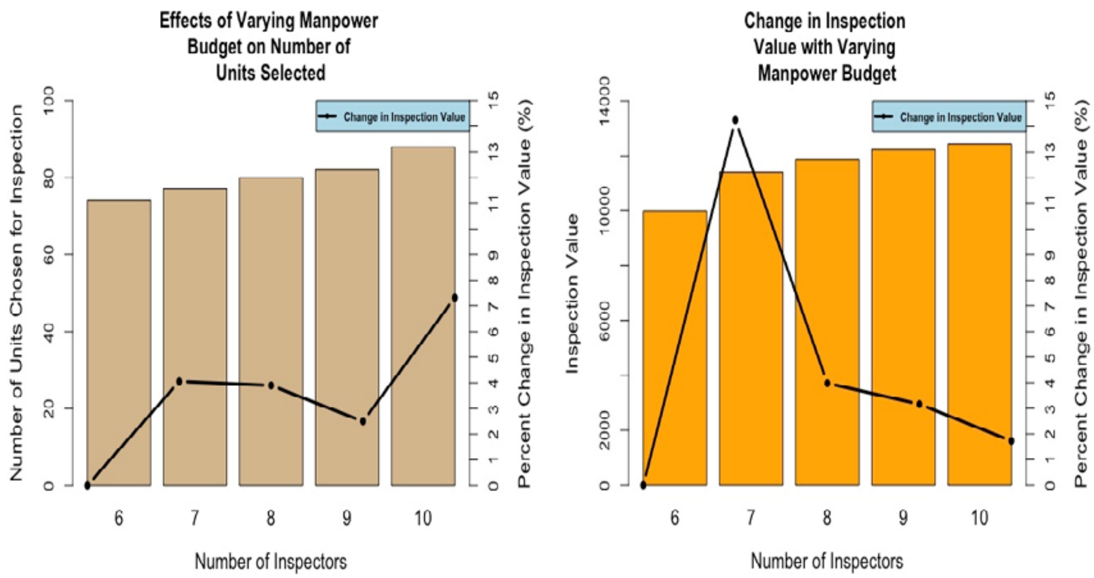
c. Five Inspectors

Our baseline analysis focuses on maximizing total inspection value while ensuring we inspect all major units using SMAT's current policy. SMAT policy dictates an ideal team consists of five inspectors. We use this as the starting point of $manpowerBudget_t$ in our analysis. In this instance, we find we inspect all but one major unit. MARFORRES cannot meet policy requirements with five homogenous inspectors.

d. Varying the Number of Inspectors

We established that MARFORRES cannot inspect all major units using five homogeneous inspectors. We now increase the number of available inspectors. We investigate this by analyzing how the change in the number of inspectors available to

MARFORRES improves their capability in inspecting all major units. As a result, we provide MARFORRES with a greater understanding of how the addition of inspectors directly improves the implementation of their current SMAT policy. As Figure 14 illustrates, when we add a sixth inspector to SMAT, we are successful in inspecting all 45 major units. In addition, 29 subordinate units are inspected. With a seventh inspector we can increase coverage by 4.1%. However, we find the greatest coverage expansion with ten inspectors where we increase by 7.3%. This corresponds to an increase in the total number of units selected to 88 units (45 major units and 43 subordinate units). Shown in the second graph of Figure 14, we find that we are increasing total inspection value as we increase our budget. We find increasing SMAT size from six to seven inspectors produces a 14.3% change in inspection value. While we increase in inspection value as we increase budget, we find diminishing returns in the change of inspection value as we add inspectors. Adding inspectors improves total inspection value in two ways, either by increasing the total number of units selected for inspection or selecting more units during their target inspection periods. Diminishing returns is the result of reaching our limits in feasibly inspecting more of these units due to distance constraints in a given quarter or reaching the maximum number of units we can select in their target inspection periods given distance and resource limitations.



The plot on the left displays the change in inspection coverage with an increase in manpower budget. A manpower budget is quantified by taking the product between the number of inspections an inspector can execute per quarter (six in our case) and the number of inspectors available to SMAT. We also display a line plot for the change in inspection coverage as we add inspectors. The plot to the right displays the change in our inspection value. As we increase our manpower budget, we increase the value of our inspections. The interval change in total inspection value is shown by the line plot.

Figure 14. Change Inspection Coverage with Increasing Manpower Budget

We now closely examine two instances where we inspect all major units. We start with a policy that includes six homogenous SMAT inspectors in its budget. Table 6 displays the results of this run.

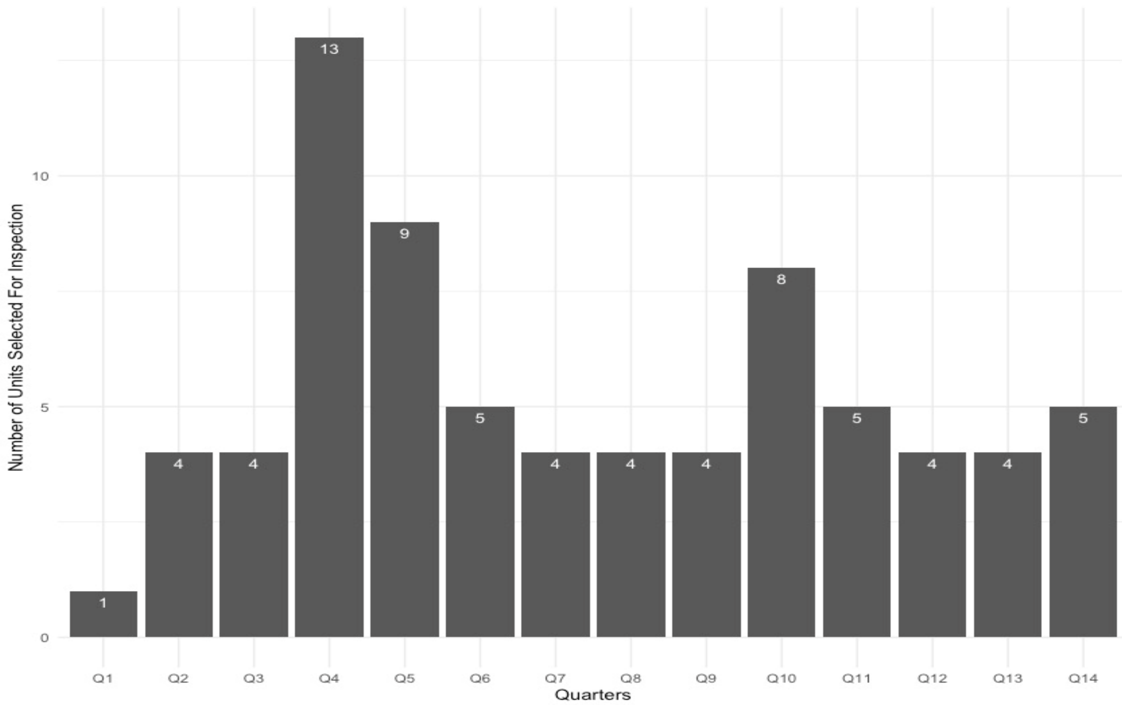
Table 6. Analysis of SMAT Policy with Six Inspectors

	Number of Units	Proportion of Selected Units
Two Quarters Before Target	25	0.338
One Quarter Before Target	14	0.189
On Target	35	0.473
Percentage of Units Selected	0.319	

The table depicts the results of running MILP-1A with a manpower budget of six inspectors. In this case, we inspect all major units, which meets policy requirements.

We inspect a total of 74 units, 45 of which are major units and 29 of which are subordinate. Under this data instance, MARFORRES G-4 inspects 32% of its total activated reserve force. While 47% of units are selected within target inspection periods, we see 34% of units fall two quarters prior to the target inspection period and the remaining 19% fall a single quarter prior to its target inspection period.

Shown in Figure 15, we see a trend in the spread of unit selection across our three-year period. A majority of the quarters have 4 units associated with them. Each of these 4 units are major units, which are the largest resource users. We see three large spikes in quarters four, five, and ten. These quarters contain a majority of the subordinate units we have selected. We find that subordinate units have a much smaller resource requirement, which allows us to schedule more of them. However, we eventually hit a limit either via our distance constraints or resource availability. In any of these data instances, we cannot inspect all 232 units due to limitations placed by our distance constraints.



This displays the distribution of units chosen across all quarters while analyzing a SMAT policy that uses six inspectors. In this instance, our artificial quarters 1 and 2 have been assigned units to them. In particular, these five units (1 in quarter one and 4 in quarter 2) are major units.

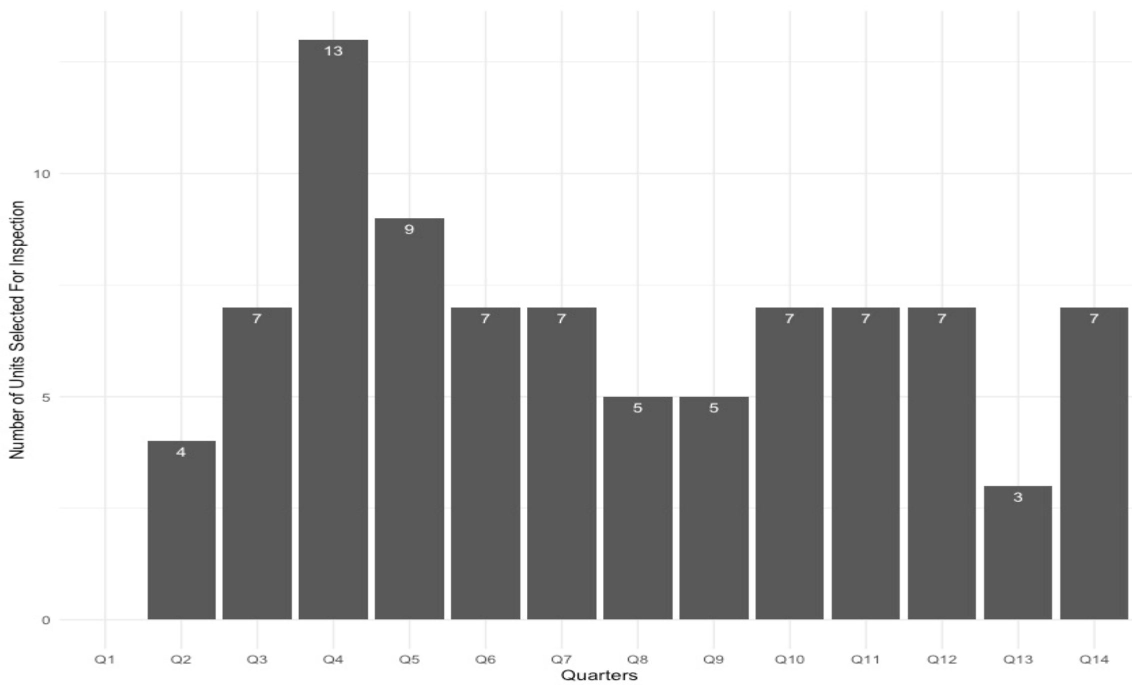
Figure 15. Analysis of SMAT Policy: Distribution of Units Chosen for Inspection with 6 Homogenous Inspectors

When we analyze the SMAT inspection program with ten inspectors, we inspect a total of 88 units. Table 7 displays the results of our analysis. We find a majority of the units we select are chosen within their target inspection periods. Of the 37 units selected within target inspection periods, 16 of them are major units. The second largest number of units selected fall two quarters prior to their target inspection periods. 23 of these units are major units, leaving the remaining six major units to fall one quarter prior to their target inspection period. Figure 16 displays the spread of units across quarters. With a larger manpower budget, MARFORRES is capable of expanding the number of units it can inspect during any particular quarter while maximizing total inspection value. In this data instance, we can inspect up to seven major units per quarter before we fully expend our budget. Quarter four is consistent in the number of units it can inspect, where a single major unit exists. The remaining twelve units are subordinate and require much less resources to inspect.

Table 7. Analysis of SMAT Policy with Ten Inspectors

	Number of Units	Proportion of Selected Units
Two Quarters Before Target	34	0.386
One Quarter Before Target	17	0.193
On Target	37	0.420
Percentage of Units Selected	0.379	

This displays the results from analyzing SMAT policy with ten inspectors. We find MARFORRES can inspect approximately 38% of all of their units. Additionally, we find that 42% of the units selected are within their target inspection periods. The additional resource adds flexibility to MARFORRES' decision space.



The figure displays the distribution of units chosen across all quarters while analyzing a SMAT policy that uses ten inspectors. We observe our artificial quarter 2 has four units assigned to it. These are major units.

Figure 16. Analysis of SMAT Policy: Distribution of Units Chosen for Inspection with 10 Inspectors

2. Resource Availability

In this section, we investigate SMAT policy by analyzing the effects of MARFFORES' total available FTE resource, $fteAvail_{t,c}$, on maximizing total inspection value in this three-year period. We discuss three approaches to this analysis. First, we investigate direct changes to total resource availability as a whole. This discussion allows us to see how overall changes to MARFORRES' available resources affects total inspection value. We then examine how resource availability in particular commodity sections play a role in the problem. Finally, we target those particular quarters that require the greatest resource to inspect and how they affect total inspection value.

a. Full Time Equivalent Data: Resource Availability

Each unit in our SMAT inspection program data is provided an FTE requirement broken down by commodity section. This data is set in the parameter, $fteReq_{u,c}$. This requirement represents the total resource required to successfully inspect the unit in a five-day period. Using MILP(1B), we consider resource availability from the perspective of commodity sections. We set $fteAvail_{t,c}$ as the sum total FTEs required for unit inspection during its target and associated out-quarter inspection periods. See Table 8 for an example of this data instance.

Table 8. Example Resource Availability Data (100% Resource).

Quarters	Supply	Comm	Motor	Ordnance	Maint	BulkFuel	Engineer	Weapons
Q1	2	0.4	0.4	0.4	0.4	0	1	0
Q2	**25.8**	**7.4**	**4.6**	**8.2**	**10.4**	**0**	**4.2**	**4**
Q3	55	14	15	18	18	0	7	13
Q4	**84**	**21**	**20**	**27**	**23**	**3**	**20**	**13**
Q5	60	14	25	19	13	3	17	9
Q6	**43**	**9**	**18**	**13**	**9**	**3**	**15**	**3**
Q7	53	13	15	20	12	1	11	8
Q8	**63**	**17**	**18**	**23**	**15**	**1**	**13**	**10**
Q9	59	16	17	22	14	1	14	7
Q10	**42**	**10**	**11**	**13**	**10**	**0**	**6**	**3**
Q11	55	11	17	18	13	1	17	0
Q12	**65**	**14**	**22**	**22**	**15**	**3**	**21**	**0**
Q13	44	9	16	16	10	3	20	0
Q14	**18**	**4**	**6**	**6**	**4**	**2**	**6**	**0**

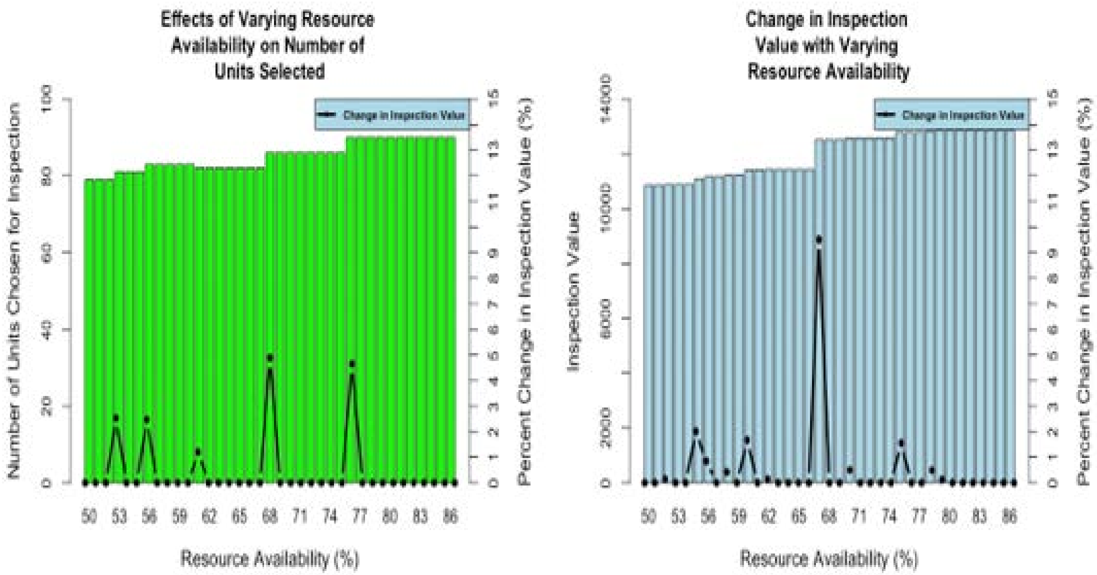
The table displays resource availability data, $fteAvail_{t,c}$, with Full Time Equivalents (FTE) as the unit measure. In this case, we display a data instance where MARFORRES has all of its resources available to use for its inspections.

b. Assumptions, Limitations, Restrictions

In this instance, we assume 1 FTE is equivalent to 1 inspector working 5 days in an inspection. Furthermore, we assume SMAT consists of heterogenous inspectors. A heterogenous inspector is defined as an inspector that can only inspect a single commodity section that he or she has expertise in. This restricts MARFORRES' capability to inspect a unit by limiting commodity section expertise to what they have available during that period. This reflects the realistic nature of SMAT inspections in MARFORRES. As MARFORRES addresses varying commitments in its mission sets, during these next three fiscal years, they may lose particular SMAT expertise that would have been required to inspect units for that period, thereby reducing coverage and forcing target inspection periods to shift. The maximization of total inspection value is dependent on the availability of these specialized inspectors to inspect units throughout this three-year period. Finally, the total availability of these inspector resources, $fteAvail_{t,c}$, is developed so that it considers units shifting into out-quarter inspection periods.

c. Considering Resource Availability Across Commodity Sections

Shown in Figure 17, the plot on the left displays the change in number of units selected as we vary total available resource. To the right, the plot displays the increase in total inspection value as we increase resource availability. It depicts that we are increasing the value of our inspections as we increase total available resource. Focusing on the plot to the left, MARFORRES can inspect all major units with 50% of their total available resources in a three-year period. This results in a total of 79 units inspected, where 45 of these are major units and the remaining 34 units are subordinate. In this data instance, we find that MARFORRES peaks in the number of units selected with 75% of their available resources. This increases the number of units selected to 90 units (45 major units and 45 subordinate units) which is a 4.6% improvement in coverage. We find our rate of change is cyclic in nature, but the largest improvement in coverage is associated with 67% of MARFORRES' total available resources where we find a 4.9% increase in coverage. Furthermore, this result is associated with a 9.5% increase in inspection value, which is the largest improvement of all of our runs. In this data instance, MARFORRES cannot inspect all units (which is the result of inspection distance restrictions).



The plot on the left displays the change in the number of units selected while increasing available resource. We find that with 49% of its total available resources, MARFORRES cannot inspect all major units. However, at 50% resource availability, MARFORRES meets policy requirements. Furthermore, we provide the interval change of coverage with additional resource. The plot on the right displays the monotonicity of our total inspection value as we increase available resource and the interval change in total inspection value.

Figure 17. Change in Inspection Coverage with Varying Resource Availability

These results speak to the level of flexibility and mobility MARFORRES has in shifting available resources in this three-year period. In this data instance, we find that, at minimum, 67% of MARFORRES' available resources in the next three years allows MARFORRES to see the greatest improvement in total inspection value. Finally, we acknowledge the main difference in these results when compared to homogenous inspectors. With homogenous inspectors, we find our result to be optimistic as it is a relaxation to the problem. In this data instance, a heterogenous inspector reflects the realistic nature that is involved in executing SMAT's mission.

d. Targeting Commodity Sections

Our second approach targets commodity sections that require the greatest number of resources to inspect. Recall, Supply sections use the most resources, followed by Motor Transport and Ordnance. As such, we use these commodity sections as the target for this analysis. We start at 49%, or the point at which we do not inspect all major units. Increasing

$fteAvail_{t,c}$ for Supply, while holding all other commodity sections constant does not seem to improve inspection coverage nor meet SMAT policy to inspect all major units. We see the same trends when we target Motor Transport and Ordnance. This suggests that adding available resources to a single commodity section will not aid MARFORRES to efficiently meet mission in a constrained environment. Next, we consecutively add available resource to targeted commodity sections combined. Adding all available resources to Supply, Motor Transport, and Ordnance sections while keeping all other sections constant did not show improvement either. However, when we add Bulk Fuel (the fourth greatest resource user) at 50%, we inspect all major units (but not all units). Under these conditions, MAFORRES G-4 will find meeting its policy requirements difficult without specialized inspectors that have Supply, Motor Transport, and Ordnance expertise in this three-year period.

e. Targeting Quarters

We then explore the effects of changing resource availability, $fteAvail_{t,c,}$, by targeting those quarters with the greatest resource requirement per fiscal year. These quarters are six in FY 21, nine in FY 22, and thirteen in FY 23. We start our analysis at 49% of MARFORRES' total available resources. We still do not inspect all major units when we add resource to quarters six and nine, individually or combined. This makes sense since resource is constrained during these periods and require an increased spread of resources throughout the three-year period to see improvement. We finally inspect all major units when we add resource to quarter thirteen in FY 23. Using 67% of MARFORRES' total available resources in quarter thirteen, we find that we can inspect all major units, thereby meeting SMAT policy requirements.

C. DEVIATION FROM POLICY

In this section, we deviate from SMAT policy to display the flexibility of our model and the effects of making changes to MARFORRES' current inspection strategy while still maximizing the value of units selected. We start by briefly exploring the relaxation of constraint (C4) to represent moving to a strategy that focuses on inspecting units regardless of whether the unit is major, or subordinate. We end our discussion with an analysis of one of MARFORRES' historic inspection strategies, which focused inspections on those Preferred Sourcing Units (PSU).

1. Relaxing MARFORRES' Major Unit Requirement

We examine the potential changes to MARFORRES policy by relaxing the restriction to inspect all major units in both MILP(1A) and MILP(1B). The purpose here is to expand MARFORRES' decision space based on current resource data. Here we use previously introduced manpower data, total available resources, and associated assumptions to analyze this problem.

a. Manpower Budget

Using MILP(1A) and setting a constant $manpowerBudget_t$, we examine a SMAT policy that consists of five homogenous inspectors. In the original problem, we do not inspect all major units. In this data instance, by relaxing our major unit constraint, we find that we improve total inspection value and select a total of 72 units. We do not inspect all 232 units. This is attributed to current SMAT policy which restricts unit selection for inspection in a quarter based on their distances from other units.

b. Total Available Resources

Under MILP(1B), we investigate how MARFORRES' total available resources, $fteAvail_{t,c}$, affects the problem while relaxing the major unit requirement. In this data instance, we assume inspectors are heterogenous and that their particular commodity expertise plays a direct role in maximizing total inspection value. Furthermore, we assume that MARFFORES has all of their resources available to them.

In the original problem, with all of MARFORRES' available resources, we return a total inspection value of 13,679 where we select 94 total units and all major units. In this data instance, we improve our inspection value to 14,039 which is 2.6% increase from our original result. We decrease the number of units selected to 83 where 48% of selected units are within their target inspection periods. In our aim to maximize total inspection value, we will inspect more units within their target inspection periods at the cost of decreasing total number of units selected in this three-year period.

2. Preferred Sourcing Units (PSUs)

In this section, we analyze one of MARFORRES' historical inspection programs which involved inspecting Preferred Sourcing Units (PSU). PSUs were units that MARFORRES intended to deploy in support of Operational Plan (OPLAN) execution, crisis response, and any other operational commitment the active duty force required. The assumption here is that MARFORRES intends on inspecting all PSUs.

a. PSU Data Framework

We use the SMAT inspection program data instance to analyze this problem. To do so, we assign units that are set to deploy or are currently assigned to support an OPLAN. In this data instance, we assume the following units are the PSUs (see Table 9):

Table 9. Table of Preferred Sourcing Units (PSU) Used in SMAT Analysis

PSU	Priority	Quarters
M00408	1	Q6
M00409	1	Q6
M01235	2	Q10
M01236	2	Q10
M01335	2	Q10
M03028	1	Q6
M14004	2	Q9
M14133	1	Q6
M21627	1	Q4
M22324	1	Q6
M22326	1	Q6
M22428	1	Q6
M22429	1	Q6
M29063	1	Q6
M29319	1	Q6
M29320	1	Q6
M29326	1	Q6
M29424	2	Q9
M29434	2	Q9
M29442	1	Q4
M29446	1	Q4
M75301	1	Q6
M77142	1	Q12

This is a list of units we use in the analysis of deviating from SMAT policy. In this case, we assume these units would be designated as PSUs. We further assume SMAT policy would require all PSUs to be inspected in the three-year period. The "Quarters" column is the target inspection periods for our PSUs.

Priority value assignment and inspection values, $Pri_{u,t}$, remain the same as established at the beginning of this chapter. In addition, we use previously introduced manpower budget data in this analysis.

b. Model Modification

In addition to using the above units, we also modify MILP-1A to reflect the following:

$$MAX \ \sum_{(u,t)\in UT} Pri_{u,t} Y_{u,t} - psuPen \sum_{u\in PSU} PS_u$$

subject to:

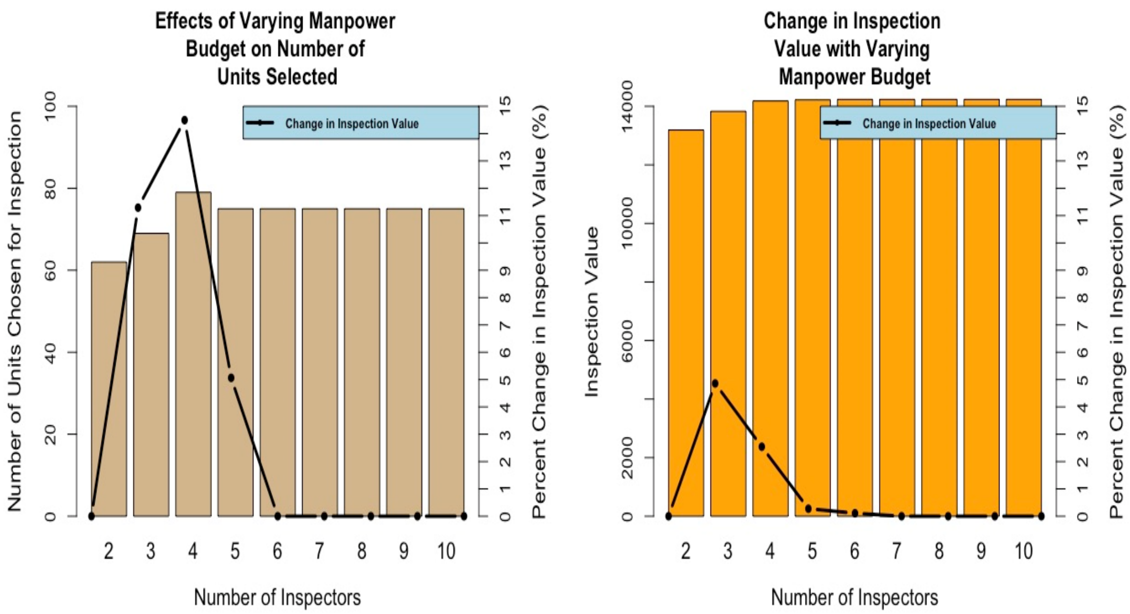
$$Y_{u,t} + Y_{u',t} \leq 1 \qquad \forall (u,u') \in FAR: (u,t) \in PSUT, (u',t) \in ST \qquad \text{(C3)}$$

$$PS_u = 1 - \sum_{t:(u,t)\epsilon PSUT} Y_{u,t} \qquad \forall u \in PSU \qquad (C4)$$

psuPen is the penalty we associate with not inspecting all PSUs in our three-year period. *PSUT* represents PSUs and the assigned inspection periods. *PSU* holds all of our PSU UICs. Finally, the continuous variable *PS* allows us to penalize PSUs that are never selected in any time period.

The objective function maximizes total inspection value while penalizing for not inspecting all PSUs. Constraints (C1) and (C2) remain the same as previously introduced. Constraint (C3) ensures that a subordinate unit is not inspected if it is more than 200 miles from a selected Preferred Sourcing Unit in a period. Constraint (C4) ensures that every Preferred Sourcing Unit is inspected once. The continuous variable, PS addresses whether we inspect all Preferred Sourcing Units. If a Preferred Sourcing Unit is not selected, we extract a large penalty from the total inspection value in the objective function. This forces the requirement to select all Preferred Sourcing Units, while informing us when this is not possible and which units are affected.

In Figure 18, we display the results of our analysis. We notice that under a PSU inspection strategy, MARFORRES requires a minimum of two homogenous inspectors per quarter to inspect all PSUs. Furthermore, if MARFORRES seeks to increase the number of units selected while maximizing total inspection value, we find that with four homogenous inspectors we can inspect up to 79 units (23 PSUs and 56 subordinate units). This a 14.5% increase in coverage from using two or three inspectors. Furthermore, in this data instance, MARFORRES is capable of successfully meeting mission with two to four homogenous inspectors. However, we find a 4.9% increase in total inspection value, our largest improvement, when we use four homogenous inspectors.



The figure displays the results of changing the number of inspectors in SMAT in a policy that focuses on Preferred Sourcing Units. On the plot to the left, we find that using SMAT's current policy which involves a team of five homogenous inspectors inspects all PSUs. In this data instance, at minimum two homogenous inspectors are enough to inspect all PSUs. We display a line plot to depict the change in coverage as we add inspectors. To the right, we observe inspection value increasing with manpower budget with a line plot to display the marginal changes that occur as we add inspectors to SMAT under this policy.

Figure 18. Change in Inspection Coverage with Varying Manpower Budget Considering the Inspection of All Preferred Sourcing Units

D. MODEL GENERALIZATION

In the last section, we deviate from SMAT policy to show the flexibility of our model on varying MARFORRES programs. We expand this discussion to introduce model generalization that includes other MARFORRES-related inspection programs, e.g.

FSMAO, FRAAP, MCAAT, and CGI. We start with a brief discussion on mapping from our current model into a generalized model and address additional requirements for those inspection programs we have mentioned. Finally, we briefly introduce a composite function that takes these various inspection programs into account and provides an aggregated score that informs the MARFORRES Commander on the status of its units.

1. Mapping MARFORRES Inspection Programs to Current Model

Among the four inspection programs mentioned, FSMAO is the only program that is capable of direct one-to-one mapping into our current model with very few changes. Hence, we begin our discussion with FSMAO. As we mention in our literature review, FSMAO is a Headquarters, Marine Corps-directed inspection program aimed at analyzing a unit's supply and maintenance sections of the targeted unit. The supply and maintenance sections are broken down by commodity sections as it is in the SMAT inspection program. We find that all of the parameters that exist in this current model can be used directly on the FSMAO inspection program.

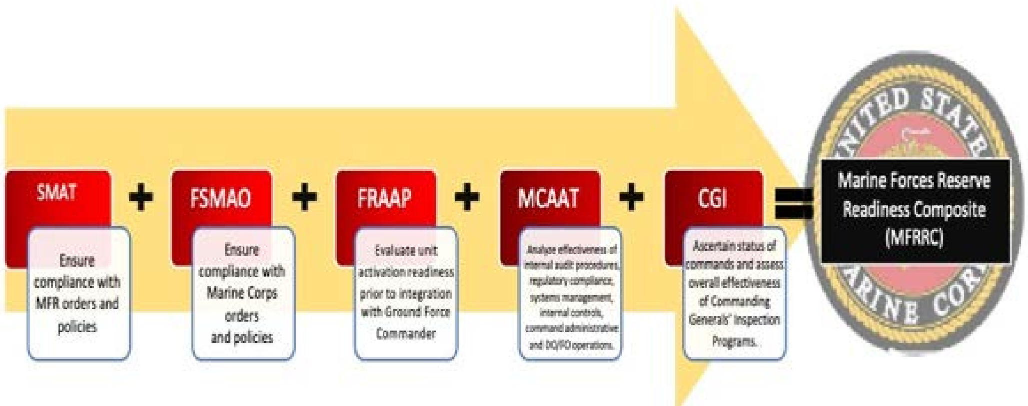
The FRAAP inspection program is a Commander, MARFORRES directed inspection that is designed to assess a unit's mobilization and deployment readiness. Occurring on a triennial basis, the inspection focuses on a unit's administrative, logistical, supply, embarkation, transportation, and recall procedures. One-to-one mapping exists in considering distance constraints, UICs, and target inspection periods. In this instance, our current model requires adjustment to reflect the nature of this type of inspection. The definition of an FTE considering a FRAAP will require understanding of how long it takes an inspector to analyze each of the mentioned focus areas. With this information we can quantify FTE requirements and availability for each unit requiring an inspection. Instead of commodity sections, a model that considers a FRAAP program would adjust to inspectable procedural themes that include administrative, logistical, supply, embarkation, transportation, and recall procedures. In our assignment criteria, we consider mostly logistical commitments. This is not the case for the FRAAP inspection program. While FRAAPs consider the inspection of units on a priority basis, we require establishment of unit priority assignment criteria to reflect the operational nature of the program. Inspection values can be developed to reflect these priority values.

The MCAAT analyzes a unit's internal audit procedures. Similar to FRAAP, we can partially map our current model parameters to this inspection program. Those changes that are required include adjusting set definitions and redefining an FTE to reflect inspection capabilities during the execution of the analysis. Units are chosen for inspection based on a priority basis. Assignment of inspection values will require re-evaluation to consider a MCAAT's prioritization criteria.

The CGI assesses a unit's readiness across several functional areas. One-to-one mapping is possible in this case, but once again requires redefining set definitions and the description of an FTE to reflect a three-day inspection. Successful FTE definition leads to the establishment of unit FTE requirement and resource availability parameters. With these adjustments, we can use our current model on this inspection program.

2. Marine Forces Reserve Readiness Composite

We have established that it is possible to map our current model into other inspection programs under MARFORRES' purview. We propose a composite model, similar to what we depict in Figure 19, that analyzes various MARFORRES inspection program data to gain greater insight into resource management among inspection programs. Theoretically, the model would produce a score based on optimized values for each inspection program of interest to MARFORRES, which would result in what we call a Marine Force Reserve Readiness Composite (MFRRC). This MFRRC would inform the MARFORRES Commander on the health of his or her units, while speaking to inspection value and resource management in MARFORRES.



This is the proposed composite function that involves using the generalization of the SMAT analysis model to analyze each of MARFORRES' inspection programs. The generalization would, theoretically, produce an individual score or value for each inspection program based on current MARFORRES data that, when totaled, would result in what we call the Marine Forces Reserve Readiness Composite (MFRRC). The MFRRC would inform the MARFORRES Commander on the health of his or her units, while speaking to resource management in MARFORRES.

Figure 19. Marine Forces Reserve Readiness Composite (MFRRC) Function

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V. RECOMMENDATIONS AND CONCLUSIONS

A. CONCLUSIONS

We formulate two multi-period mixed-integer linear programs each of which optimize total inspection value for SMAT inspections. In MILP(1A), we show that MARFORRES requires SMAT structure modifications if it intends on implementing a policy that requires the inspection of all major units. The more inspectors available, the more flexibility MARFORRES has in inspecting units within target inspection periods. For instance, with seven homogenous inspectors, MARFORRES expands their coverage by 4.1% and with ten homogenous inspectors we observe a 7.3% increase. In addition, MARFORRES finds an improvement in total inspection value as it increases the number of homogenous inspectors available for inspection. We observe a 14.3% increase in total inspection value with a shift from six to seven homogenous inspectors. Furthermore, we find steeply diminished marginal returns after adding more than seven homogenous inspectors. While a shift from six to ten inspectors is a 25% improvement in total inspection value, this is only an approximate 2% increase from using nine homogenous inspectors. These diminishing returns are attributed to the limitations emplaced by the maximum number of units MARFORRES can select in a given quarter or within their target inspection periods.

In MILP(1B), we examine the effects of MARFORRES' available resource on total inspection value. In this instance, we consider heterogenous inspectors who specialize in particular commodity sections. Using MILP(1B), we find that MARFORRES does not meet policy requirements with less than 50% of their total available resources. However, we expand the number of units selected while maximizing total inspection value with 67% of MARFORRES' available resources (which is a 4.9% increase in inspection coverage and a 9.5% improvement in total inspection value). This instance is a restriction of our previous analysis and a more realistic representation of MARFORRES resource allocation as it applies to inspector assignment to unit inspections.

We explore deviations from SMAT policy to expand MARFORRES' decision space and show how policy modifications affects the problem. In one instance, we explore relaxing

MARFORRES' major unit constraint using both models. In both cases, MARFORRES improves total inspection value. In MILP(1A) while improving value, MARFORRES expands coverage space. Contrarily, MILP(1B) shows a 2.6% increase in total inspection value with more units inspected within their target inspection periods.

Additionally, we examine SMAT policy focusing on one of MARFORRES' historical programs: Preferred Sourcing Units (PSUs) inspection program. Here we display the flexibility of our model and its capability to be generalized. We find that under a policy that focused on inspecting all PSUs, we are successful with two homogenous inspectors. We see a 14.5% increase in inspection coverage and 4.9% increase in inspection value if MARFORRES moves towards using four homogenous inspectors. In this data instance, SMAT's current policy, of which calls for five inspectors, would be enough to implement a requirement to inspect all PSUs, but would find diminished returns in total inspection value when compared to using two to four homogenous inspectors.

B. FUTURE WORK

The inspection values we use in this analysis are derived from testing a range of values for consistency and robustness. While these values were the least sensitive to change, we suggest research into a more precise value scheme.

These models may be implemented on other inspection programs within MARFORRES. This will inform on two levels. The first level confirms the strength of the model we have developed here and its capability to be expanded. The second speaks to informing MARFORRES on the total inspection value of its other inspection programs and how related policies can be modified or improved upon from an analytical standpoint.

The data instance we used for the FTE required and availability data were quantified based on how much an inspector works during an actual inspection. While this data is informative in providing the worth of a homogenous, or heterogenous inspector on inspection value and the selection of units for inspection, we are still missing a key component of resource management- the cost of an inspection. Future research should collect cost data to understand the cost of an inspection and cost margins when MARFORRES gains or loses resources. This will inform MARFORRES on both inspection value and the total cost of these inspections.

Constraint (C3) in both models applies to the major to subordinate unit pairs. In particular, every pair of selected units comprising of one major and one subordinate unit will have a distance of no more than 200 miles between them, forming inspection clusters. Within these inspection clusters, every pair of subordinate units selected will have a distance of no more than 400 miles between them in a given quarter. Units selected that are solely major units, or subordinate units, could be arbitrarily far apart. To consider restricting the distance SMAT travels in this last instance, as well as in solutions selecting only major units or only subordinate units, we could reformulate our constraint for both models as follows:

$$Y_{u,t} + Y_{u',t} \leq 1 \qquad \forall (u, u') \in FAR, t \in T: (u, t) \in UT, (u', t) \in UT \qquad \text{(C3')}$$

We can also consider another version of constraint (C3) in which we ensure subordinate units are selected only if it is within 200 miles of a major unit that is selected. In this instance, we can reformulate our constraint for both models as follows:

$$Y_{u,t} \leq \sum_{u' \in M:(u,u') \notin FAR} Y_{u',t} \qquad \forall u \in U - M, t \in T \qquad \text{(C3'')}$$

The inspection of PSUs set conditions to discuss the capability of generalizing the model. Model generalization allows MARFORRES to expand this analysis to include other inspection programs (in particular, FSMAO, FRAAP, MCAAT, and CGI). We find that mapping our current model parameters and sets is possible but may require some redefining to reflect other inspection programs. We end the discussion with the proposition of a composite function that considers all of MARFORRES' inspection programs and produces a score that would inform the MARFORRES Commander on the status of his or her units. While we focus on the SMAT inspection program to show the strength and capabilities of these models, the end state is to develop a model that optimizes MARFORRES inspection strategy as a whole by maximizing the total value of their inspections. Successful model generalization of our current model meets that end state and is the key to creating a useable analytical tool for MARFORRES that answers key questions regarding resource management and allocation while keeping inspection value in mind.

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