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THESIS

USMC LOGISTICS RESOURCE ALLOCATION OPTIMIZATION TOOL

by

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December 2015

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To support the U.S. Administration's announced rebalancing, or pivot, to the Asia-Pacific region, the U.S. Marine Corps is pushing its footprint beyond established logistics support locations. Yet, the Corps' ability to rapidly respond to primary missions, such as international military cooperation, humanitarian assistance, and defense of U.S. interests, must be maintained. This Marine diaspora from Okinawa, its current concentration, must consider the logistical vagaries of time, space, and expense. This thesis develops an optimization-based tool by which item-specific details are combined with theater logistical constraints to analyze present logistical performance and "what-if" capability for future troop redeployments within the region. The mathematical model is applied to optimally allocate Class IX repair parts for the Marine Corps across the Pacific theater. In particular, the combined relationship of Defense Logistics Agency and the Marine's intermediate level supply units is analyzed. The optimization model minimizes a logistical system cost of multiple priority demands from disparate locations. The model is flexible enough to allow any number of stock items, additional user locations, and supply nodes at operational and strategic levels. While the focus is the force rebalancing in the Pacific, the intent is a general tool that can support other theaters.

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USMC LOGISTICS RESOURCE ALLOCATION OPTIMIZATION TOOL

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ABSTRACT

To support the U.S. Administration's announced rebalancing, or pivot, to the Asia-Pacific region, the U.S. Marine Corps is pushing its footprint beyond established logistics support locations. Yet, the Corps' ability to rapidly respond to primary missions, such as international military cooperation, humanitarian assistance, and defense of U.S. interests, must be maintained. This Marine diaspora from Okinawa, its current concentration, must consider the logistical vagaries of time, space, and expense. This thesis develops an optimization-based tool by which item-specific details are combined with theater logistical constraints to analyze present logistical performance and "what-if" capability for future troop redeployments within the region. The mathematical model is applied to optimally allocate Class IX repair parts for the Marine Corps across the Pacific theater. In particular, the combined relationship of Defense Logistics Agency and the Marine's intermediate level supply units is analyzed. The optimization model minimizes a logistical system cost of multiple priority demands from disparate locations. The model is flexible enough to allow any number of stock items, additional user locations, and supply nodes at operational and strategic levels. While the focus is the force rebalancing in the Pacific, the intent is a general tool that can support other theaters.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACF   Area Cost Factors

ACWT   Average Customer Wait Time

CASREP   Casualty Report

CLR-35   Combat Logistics Regiment 35

CNA   Center for Naval Analyses

CONUS   Continental United States

CWT   Customer Wait Time

DD   DLA Distribution

DK   Diesel Kit

DLA   Defense Logistics Agency

DLR   Depot Level Repairables

DDAU   DLA Distribution Australia, exists only as model variable

DDGM   DLA Distribution Guam

DDOJ   DLA Distribution Okinawa, Japan

DDPH   DLA Distribution Pearl Harbor, Hawaii

DDPI   DLA Distribution Philippines, exists only as a model variable

DDYJ   DLA Distribution Yokosuka, Japan

DOD   Department of Defense

DODAAC   Department of Defense Activity Address Code

EMALL   Electronic Mall

EPF   Expeditionary Fast Transport

FMSO   Foreign Military Studies Office (U.S. Army)

FSG   Federal Supply Group

GAMS   General Algebraic Modeling System

GR   Grounding Rod

GUI   Graphical User Interface

HADR   Humanitarian Assistance/Disaster Relief

HL   Headlight

JHSV   Joint High Speed Vessel

MARPOM   Marine's Allocated Resources Pacific Optimization Model

MEF	Marine Expeditionary Force
MK	Medical Kit
MLG	Marine Logistics Group
MRF-D	Marine Rotational Force-Darwin, Australia
NSN	National Stock Number
RIP	Repairable Issue Point
SMU	Supported Activities Supply System Management Unit
SMUD	SMU-Darwin, exists only as a model variable
SMUG	SMU-Guam, exists only as a model variable
SMUH	SMU-Hawaii
SMUO	SMU-Okinawa
SMUP	SMU-Philippines, exists only as a model variable
TEU	Twenty-foot shipping container Equivalent Unit
USMC	United States Marine Corps
UFC	Unified Facilities Code
WC	Wheel Chock
WIG	Wing-In-Ground

EXECUTIVE SUMMARY

As the United States Marine Corps' (USMC) III Marine Expeditionary Force (III MEF) redistributes its troops from their primary location in Okinawa, Japan, more widely in the Pacific, the logistical support challenges mount quickly. Despite the size of the Pacific, only a handful of locations exist for troop basing and logistical support facilities. There are two primary sources of supply in place at these locations, which support the Marines' end-users at the tactical level: Defense Logistics Agency Distribution Centers (DDs), and the Marines' Supported Activities Supply System Management Units (SMUs). The DDs are present in more locations than the SMUs, but SMUs are more logistically responsive to Marine tactical units' requirements than DDs, based on average customer wait time. To efficiently support their troops, the USMC can benefit from an optimization tool to guide inventory placement. The tool can use inputs such as holding and transportation costs and responsiveness in existing or newly constructed facilities. To this end, this study has developed the Marines' Allocated Resources Pacific Optimization Model (MARPOM) tool, a convenient, agile, and quick method for evaluating possible logistic deployment plans in various scenarios. MARPOM is designed to assist decision makers when weighing options of whether to build new logistics facilities or expand or reduce existing sites, and what type of demand (high- or low-priority requisitions) to satisfy from which sites.

MARPOM uses the potential DD sites (Yokosuka, Okinawa, Guam, Hawaii, Philippines, and Australia), possible troop placement locations (Okinawa, Guam, Hawaii, Philippines, and Australia), and five associated SMUs, while evaluating the allocation of III MEF's five most frequently requisitioned Class IX items. Marine Corps Air Station-Iwakuni was omitted from consideration because of extremely low demand for the five items. The effect of any individual DD or SMU can be turned on or off within MARPOM, becoming a powerful "what-if" tool to show the savings or costs of opening or closing a site. While only five supply items are considered, their characteristics and requirements are varied enough to show a range of possible logistic responses. MARPOM can expand to include as many items or locations as necessary.

The structure of the logistic deployment in the Pacific theater is such that, in addition to supporting SMUs, DDs also directly support tactical units. The prevalence of this structure sways the development of MARPOM away from a typical three-tier logistics model with strict suppliers and customers at each level to a flatter, more structurally flexible model. We use the MARPOM tool to show that this characteristic has significant implications.

We test two instances of MARPOM in order to (a) obtain site and material capacity recommendations, and (b) explore sensitivity of the solution. The first case uses current USMC troop deployment. The second case uses a proposed troop deployment in response to the distributed laydown concept derived from the U.S. military's renewed focus on the Pacific theater. In both cases, several assumptions are made to account for unavailable data (facility size, space dedicated to studied materiel, SMU operations, holding and transportation costs, etc.). Accordingly, MARPOM recommendations are dependent upon them. Yet, parameters, such as demand and unmet demand penalties, are varied to show a breadth of MARPOM results and uncover relationships among the parameters, leading to reasonable observations and conclusions.

MARPOM's results with respect to inventory capacity allocation (regarding surface-transported, low-priority requisitions and air-transported, high-priority requisitions) show an interesting result: when DDs are co-located with major demand centers, and under our assumption that DDs have lower holding costs than SMUs and a delay penalty at DDs for low-priority items, MARPOM favors placement of high-priority inventory capacity at DDs and low-priority inventory capacity at SMUs. MARPOM shows that matching SMU capacity in Okinawa and Hawaii to reflect local demand and matching capacity at the DDs to the demand generated primarily by co-located forces is optimal. Due to transportation costs far exceeding holding costs, if DD capacity is available locally, it is highly preferred by MARPOM, even if holding costs are substantially less at another DD center. If a single DD location is to be used in a centralized distribution concept, MARPOM shows that the DD in Okinawa minimizes the overall system costs of the proposed deployment scenario, with DD Guam a close second.

Transportation costs become the driving force in MARPOM's results with most items' volume (not weight) being the primary factor. This leads to MARPOM accepting an unmet demand penalty for low-cost, large-volume items in some situations. Since the penalties are a multiple of the cost, this leads to high transportation costs and low penalties. This also reveals that beyond the potential inventory savings of a centralized inventory approach, concentrating on high cost, low volume items as potential candidates of a centralized inventory would minimize transportation costs and possible delay penalties.

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I. INTRODUCTION

A. BACKGROUND

This thesis began as an accompaniment to a Headquarters Marine Corps, Installation & Logistics funded study to assist the logistical decision making process with regards to a broadening USMC footprint in accordance with the Department of Defense' rebalance to the Pacific. The proposed repositioning of Marines throughout the Pacific captures the associated challenge of supporting the troops and their equipment with supplies and services over a large geographic area. In particular, Class IX repair parts were chosen for having near universal demand among all types of customers while representing a large portion of materiel movement within theater. The inescapable challenge facing any operation in the Pacific is the tyranny of time and distance. Both aspects affect cost and operational feasibility. There is a proviso that states materiel can be moved quickly or cheaply, but not both. This principle is in play in the Pacific theater and is closely associated with the two primary modes of transport in the region, sea and air. If it were merely a matter of cost, all materiel would shuttle around the region by sea transport. However, whether due to an equipment's importance or situational importance (e.g., due to conflict or disaster), some requisitions will have a high priority, necessitating that time, not cost, must be the driving concern to fill the demand. All of these factors and many more can influence the decision of where and in what quantities to place stock.

One of the drivers for the redistribution of forces is the frequency with which U.S. forces respond to natural disasters in the Pacific region. Tsunamis, such as the horrific 2004 Indonesian tsunami and the disastrous 2011 Japanese tsunami, Nepal's earthquake in 2015, and the numerous typhoons that frequently affect many nations in the region are just some of the Humanitarian Assistance/Disaster Relief (HADR) missions to which Marines have been and will continue responding. As recently as August 7, 2015, Marines were providing HADR efforts to victims of Typhoon Soudler on the island of Saipan in the Northern Mariana Islands (Pellerin 2015). To respond to HADRs, a large amount of materiel must be moved quickly. Reliance on a robust logistics network, which can also stage HADR materiel nearby, will minimize reaction time and transportation costs in the

event of a disaster. These requirements mimic those which drive an effective supply network; forward staging supply close to the demand. Marine logistics units and the Defense Logistics Agency play key roles in this effort.

The foundation of any meaningful system optimization relies on the acquisition of pertinent, precise data. This proved to be the most difficult challenge of this thesis. However, even in the face of incomplete data or missing data, workable models are possible and can provide useful solutions. A historical workshop analysis of the logistical requirements of medieval Crusaders made many informed assumptions whose relationships ultimately provided insight to previously unexplainable troop movements (Pryor 2006). The background information included assumptions of the weight carried by pack animals vs. war horses and the amount of feed consumed by different animals while being transported at sea versus open grazing on land. A book review of this workshop's proceedings provides the essence as:

> quantitatively considering the role of logistics in medieval
> warfare in general, and the Crusades in particular, can significantly
> expand our understanding, even if attempts at quantification must
> rely on limited data and assumptions that may prove faulty.

Assumptions were made in this thesis when faced with missing information and unknown quantities, but rational research provided reasonable values which can still yield useful insight to the problem.

B.   3RD MARINE LOGISTICS GROUP

The logistics combat element of III Marine Expeditionary Force (III MEF), headquartered at Camp Courtney in Okinawa, Japan, is the 3rd Marine Logistics Group (3rd MLG) also in Okinawa. The USMC defines the mission of 3rd MLG as providing "responsive combat logistics support to III MEF and other marine forces within our area of operations, and to joint, combined, and federal agencies as directed, through expeditionary means, forward basing, and global sourcing in order to sustain supported units during exercises and contingencies" (United States Marine Corps 2015). Referring to Figure 1, it becomes obvious that the majority of logistical capabilities reside in Okinawa, Japan with Kaneohe Bay, Hawaii being the only other major Marine logistical

center. The Combat Logistics Battalion 3 of the Combat Logistics Regiment 3 and 3rd Supply Battalion of Combat Logistics Regiment 35 (CLR-35) maintain the Supported Activities Supply System Management Units (SMUs) at Kaneohe and Okinawa, respectively, which are considered intermediate-level sources of supply. The Combat Logistics Company 36 supports the Marine Corps Air Station in Iwakuni.
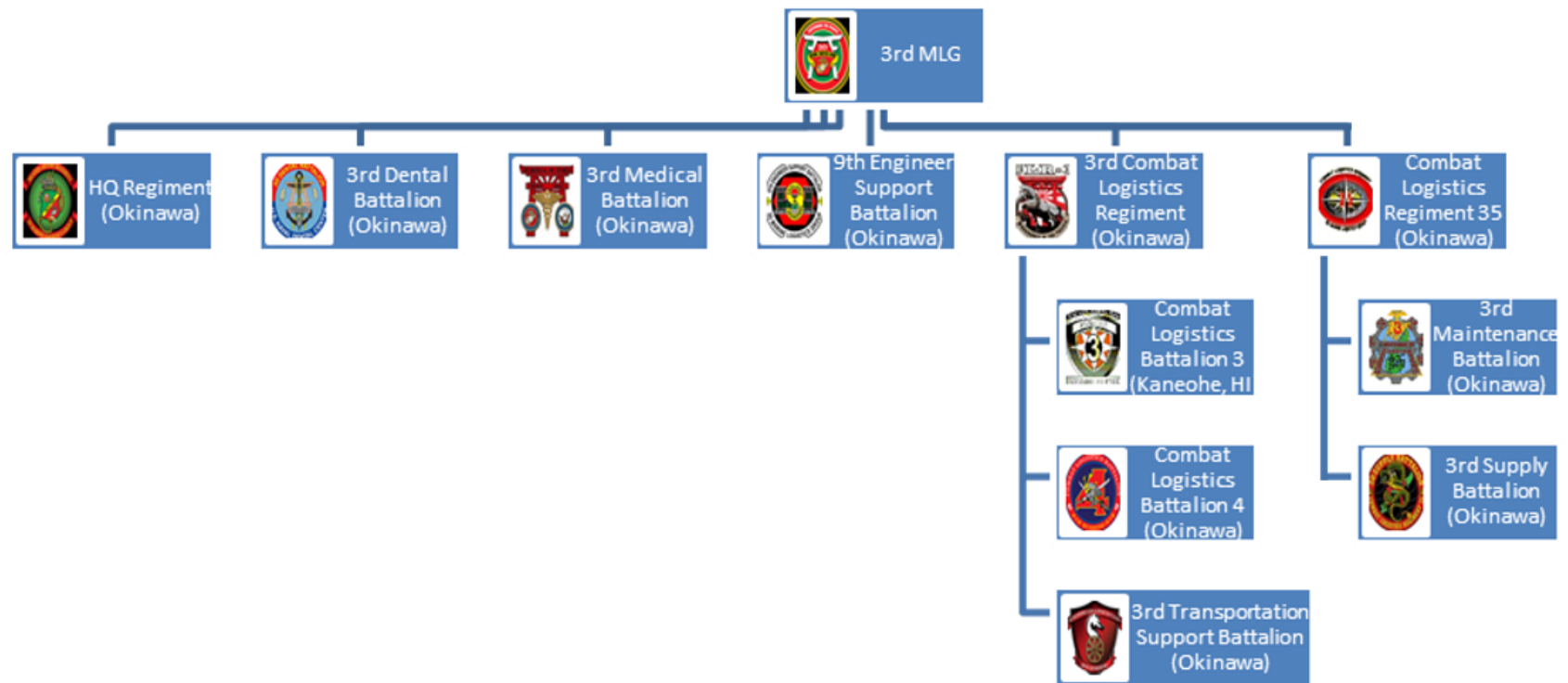
Figure 1.   Organizational Structure of III MEF's 3rd Marine Logistics Group from (from United States Marine Corps 2015)

C. DEFENSE LOGISTICS AGENCY

As a theater or strategic level of supply, the Defense Logistics Agency (DLA) performs at the wholesale level, which infers its stock is available to any Department of Defense (DOD) entity. It is possible for DLA to manage retail-level stock. If a service, such as the USMC, provides funds for the acquisition and stocking, then that stock will be for the sole use of that service and no other. This type of activity is found at DLA's distribution (DD) center in Albany, Georgia, which acts as the primary source of expendables and secondary repair parts, or Class IX materiel, for the Marine Corps Logistics Command. The DD sites in the Pacific receive the bulk of their USMC-specific DLA stock from Albany, including clothing, textiles, electrical components and supplies, nuts, bolts, weapon parts, and other secondary repair parts (Defense Logistics Agency 2015).

In the Pacific, DLA maintains strategically located distribution sites in Okinawa (DDOJ), Yokosuka (DDYJ), Guam (DDGM), and Pearl Harbor, Hawaii (DDPH). All of these sites were established under the tenet of providing forward stock positioning to reduce overall transportation costs and customer wait times for any DOD customers in the operational area. Commands stationed locally or operating in the Pacific region also benefit from improved physical distribution capabilities offered by the widely distributed DLA facilities. They manage transshipment services by both sea and air and walk-through requisition fulfillment for local commands. Guam is the newest DD facility in the Pacific, having been established in 2004. Yokosuka is by far the largest and manages 3.7 million cubic feet of diverse, covered storage (Defense Logistics Agency 2015). Okinawa is a detachment of DDYJ and is the smallest DD activity in terms of manpower, but due to its proximity to USMC units, stocks a much greater quantity of USMC-demanded materiel than does DDYJ (DLA Contact Center 2015).

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II.   THE PROBLEM

A.   BREADTH

The rebalancing of U.S. forces in the Pacific is intended to respond to President Obama's desire to address the under-weighting in the region (Lyle 2013). Consequently, the research focus is on supporting units that are based in the Pacific area of operations and outside the continental U.S. (CONUS). The primary components or subordinate commands of Marine Forces Pacific are I MEF in Camp Pendleton, California, III MEF in Okinawa, a tiny presence on Guam, and the Marine Rotational Force in Darwin, Australia (MRF-D). I MEF was excluded from this study due to its CONUS status, which insulates it from the challenges of Pacific logistics. Presently, nearly all III MEF subordinate units are located on the southern Japanese island of Okinawa or on Hawaii's island of Oahu. The President's National Security Advisor in 2013, Tom Donilon, framed this rebalancing initiative as a response to a global, strategic assessment of U.S. priorities while considering regions that are expected to impart a growing influence on world order (Lyle 2013).

As may be imagined, the previously mentioned assessment's conclusion showed the preponderance of U.S. interest was on the Middle East and much less so in the Asia-Pacific region. The drawdown of troops and the reduced strategic focus on Iraq and Afghanistan provided the opportunity to react and rebalance to face new world developments. A 2010 agreement between Japan and the U.S. to close Marine Corps Air Station Futenma on Okinawa is the first domino to fall, which will shuffle Marines around the region and significantly diminish their concentration in Okinawa (Sisk 2014).

One notional concept of numbers and locations is contained in Figure 2 and uses a Marine Corps distributed laydown concept as described in Appendix A of the 2013 Center for Naval Analyses (CNA) study by Fredlake and Randazzo-Matsel. The exact numbers to be based at each site are ultimately immaterial and will only provide an informed basis for a starting point in the analysis. Once USMC pivot plans are finalized

and stable, our model, the Marine's Allocated Resources Pacific Optimization Model (MARPOM), can easily accommodate these changes and allow a "what-if" analysis.
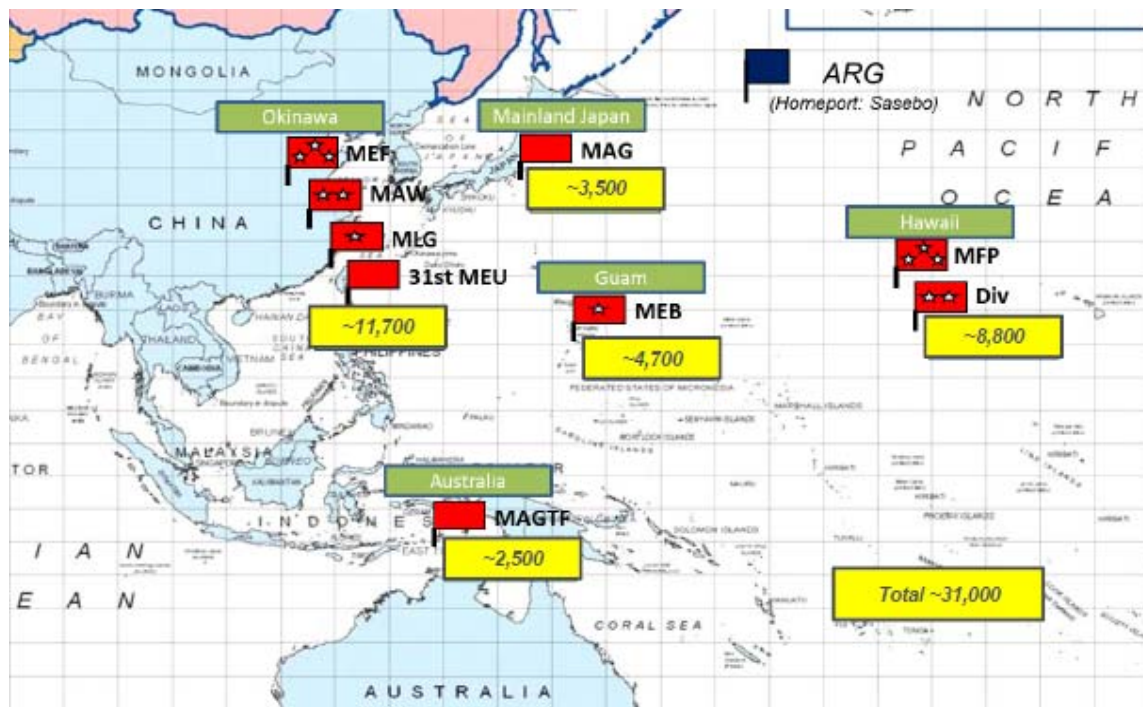
Figure 2.   Notional USMC personnel distribution from
(from Fredlake and Randazzo-Matsel 2013).

B.   STUDY'S GOALS

An aspect of the USMC Pacific based logistics operation that can benefit from further analysis is an optimization of materiel distribution among existing facilities given new troop placements within various scenarios of transportation availability, priorities, capacity limitations, and materiel characteristics. This thesis' purpose is to provide a prototypic tool that can provide insight into logistical decisions pertinent to the staging of key inventory in the Pacific area of operations.

Some of the questions this thesis investigates include:

- How to account for shift in demand based on proposed troop movements?
- If proportion of high-priority requisitions changes, does it affect optimal stock placement?

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- Does an item's volume or weight play a part in the optimal staging?

By design, the tool developed in this research is sufficiently flexible to accommodate data from other theaters and provide similar insights to the associated theater's logistics system.

C.   SCOPE

USMC's intent for the study that formed the genesis of this thesis was as a follow-on to a CNA study (Fredlake and Randazzo-Matsel 2013). As envisaged by the sponsors, the new study's goal was a master decision-making tool that could optimize time and cost of intermediate repair facility locations. This would have been based on a mission-dependent equipment mix with associated mission-specific, and equipment availability priorities. It would take into consideration the types of repairs to be conducted at the facilities and the properly skilled personnel assignments to effect repairs. It was also hoped it could aid the decision process of whether additional SMUs would be advantageous and even to consider the impact of additional DD sites. Obviously, the latter would be DLA's decision, but the impact to USMC operations may have warranted a discussion with DLA, it was thought. In light of the scale of the personnel redistribution, these considerations seemed reasonable.

The imagined scope far exceeded this study's ability to model all aspects of mission, equipment types, failure modes, repair times, carcass cycles, etc., into a flexible tool capable of handling such interdependent decisions. The data acquisition requirements alone are staggering to consider. Consequently, this study limits its analysis to III MEF demand for Class IX Repair Parts and their inventory at various existing and notional DD sites and USMC SMUs. As perceived at the time of writing, additional troops and/or SMU facilities are being considered in both established and greenfield project situations. Some of the changes are contemplated for the locales described in the next subsections.

1. Australia

The proposed numbers of Marines destined for Australia as part of MRF-D vary with time and source from 1,000 to 2,500 (Nye 2011). Currently, about 1,500 troops are rotating through training missions near Darwin in Australia's tropical north-west. However, a U.S.-Australian pact signed in 2014 solidified a 25-year agreement for approximately 2,500 Marines and Air Force personnel to rotate through during the dry season (Coorey 2014). This roughly comprises a Marine Expeditionary Unit and would represent the most remote USMC presence from established sources of supply. The support effort required in Australia is subject to a seasonal demand due to the six- to nine-month rotational nature of the deployments. The pact between the U.S. and Australia allows for a ramping of forces to the 2,500 personnel limit by 2016. So, this most distant of efforts is not insignificant.

2. Philippines

Currently, there is no permanent U.S. military presence in the Philippines, USMC or otherwise. However, the Philippine Defense Secretary, Voltaire Gazmin, announced the opening of military camps on Subic Bay's airport and seaport. These camps are intended for a new U.S. military presence as per an accord signed in 2014, but it has had its constitutionality challenged, delaying the U.S.'s arrival (Gomez 2015). Considering Subic Bay was the largest U.S. overseas naval base until it closed in 1992, the U.S. presence contemplated for this location could be sizable and likely a joint amalgamation of all services. As with any new, or underserved but expanding site, both DLA and USMC could consider complementary logistics operations, depending on the overall numbers and permanency of any troop commitment. The geo-political forces at work in the South China Sea region cast greater USMC participation in the Philippines as an ever-more-likely possibility.

3. Guam and Hawaii

The 2006 plans to move Marines from Okinawa to Guam estimated 8,000 troops would be accompanied by 9,000 dependents. This proposal of a permanent influx to Guam was determined to overly tax the infrastructure and natural resources. The plan has

since morphed and the scaled-down plan is now 5,000 mainly single troops and only 1,300 dependents. In order to redistribute half of the roughly 20,000 Marines on Okinawa, the slightly smaller numbers to Guam have given credence to plans for another 5,000 Marines to move to Hawaii. However, those plans are still in the early planning stages, but suggest a likely scenario.

D.   LITERATURE REVIEW

There is little difficulty finding previous work which seeks to optimize logistics systems. Even when including the Pacific as a search requirement, numerous scholarly works are revealed. The five most apropos works to this thesis' line of inquiry follow.

1.   Logistics Support for the Marine Corps Distributed Laydown

This CNA study (Fredlake and Randazzo-Matsel 2013) uses the term distributed laydown to describe the redistribution of Marine forces throughout the Pacific and explores how best to support repairable items either through availability of replacements or repair facilities with repair parts. The report saw DD facilities as an underleveraged facilitator with established facilities in most of the pondered redeployment sites, Australia being one exception. Through the wholesale side of DLA's operation they maintain stock for many high demand items which are common to multiple services. It is possible other, non-Marine, customers may deplete DLA stock, leading to much longer order fulfillment times of standard priority requisitions. In which case, the organic stock levels of an SMU could act as a buffer to DLA stock-outs. CNA only makes a cursory review of Class IX repair part support with an emphasis on RIP items, which by definition are not consumable. Importantly, CNA does not see any benefit to building Marine SMU facilities if a pre-existing DD site could perform essentially as a SMU in a retail-level capacity. The idea of using a DD in a retail manner is an attractive option and the most salient conclusion to reference with respect to this thesis.

2. Inventory Management of Repairables in the U.S. Marine Corps— A Virtual Warehouse Concept

The work by Larry G. Paige II (Paige 2000) studies repairable inventory to evaluate the effectiveness of pushing inventory as close to the end user as possible and relying on lateral transfers to meet demand. Pushing inventories to the consumer or tactical unit level reduces the structural flexibility of the logistics system. Holding inventories in rearward locations, allows the SMU or DD sites to efficiently adapt to changing demands across a wide customer base. However, Paige hopes to validate the inventory concept of virtual float and that of a virtual warehouse. The virtual warehouse is the idea that distributed inventory can be centrally managed by directing lateral transfers between units, if necessary. His conclusion finds that whatever overall reduced inventory the central inventory management system wrought, its savings are exceeded by the extra transportation costs of lateral transfers. This dissuades any considerations of tactical unit inventories to evaluate theater-wide logistics efficiency. This thesis will instead weigh the impact of the intermediate level supply, the SMU, and theater or strategic level supply, DD sites.

3. New Models in Logistics Network Design and Implications for Third Party Logistics Companies

Another interesting study (Fong 2005) designs logistics networks from the perspective of third-party logistics companies to optimize profits by maximizing shipping container fill rates and using consolidation points near manufacturers to minimize transportation costs. More germane to the present study, she also seeks to model a product that has two priority levels of demand that determine whether to open or close local warehouses. She first assumes customer's demand is homogenous, either all high-priority or low-priority. She also models high-priority, short lead time demand as satisfied entirely from local warehouses and low-priority, long lead time demand as fulfilled by regional hubs. By doing so, she assumes no capacity exists locally to satisfy long lead time demand. Our model considers the possibility of dual lead time/priority demand, as well, but allows both priority levels to be exhibited by a single customer or

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location. This thesis will attempt to optimize inventory placement among all warehouses, SMUs and DDs, regardless of demand proximity and on a theater-wide basis.

4.   Operational Logistics: The Art and Science of Sustaining Military Operations

There exists an excellent book that is worth reviewing before creating a representative logistical support model (Kress 2002). It shows how to marry the artistic and the scientific sides of operational logistics to make systems more effective. It begins with an overview of the theoretical underpinnings of both aspects and later, delves deeper into appropriate methods of combining the qualitative and the quantitative aspects into a single descriptive approach to operational logistics. In particular, his examination of a visual network was ideally suited for the transportation problem explored through this thesis. He points out that the visual network is appropriate for answering questions of size and content of supply nodes, where to locate supply nodes, and how best to direct the logistical flow. The book was fixated on a very clear separation of each echelon from the others in the hierarchy, which was less clear in our historical dataset. However, its explanation of flexibility partially explains the advantage of the existing structure and its implementation in the Pacific.

5.   Journal of Transportation Science

The Institute for Operations Research and the Management Sciences publishes a journal called Transportation Science which harbors the learned solutions to a wide variety of transportation related optimization problems (INFORMS 2015). There are vehicle routing problems interested in time windows in which demand must be met. A portion of this thesis' model could have been solved separately in this manner if there had been hard requirements for time of delivery. Within this publication's issues, there are models which determine protective stock levels to minimize the effects due to external disruptions, which lead to delays or materiel losses. This would be a useful approach to incorporate either unpredictable transportation networks or the effects of war on a supply chain, neither of which is included in MARPOM explicitly. It is expected that the incorporation of additional computational elements to optimize elements of this thesis'

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problem could lead to incrementally better solutions, but whether the effectiveness gains would be worth the additional work is unknown. This journal alone show that a complete review, let alone a full understanding, of the many optimization methods which are applicable to a logistical transportation problem is elusive at best. The method presented through MARPOM is merely one of many which could produce defensible and useful results.

III. OPERATIONAL LOGISTICS STRUCTURE IN THE PACIFIC THEATER

A. GENERAL STRUCTURE

The classic structure of strategic, operational, and tactical levels, consisting of CONUS and theater consolidation points (the DDs), intermediate distribution points (the SMUs), and either static or deployed tactical units, does not always exist because of varying stocking policies. Sometimes a DD may be nearby, but may not stock the requisitioned item. In that case, the SMU may decide to locally stock the item. If the SMU does not stock the item, the source becomes a distant in-theater DD or even a DLA facility in CONUS. It is also possible for tactical units to directly requisition any DLA facility for parts. The thesis data, which only indicates DLA providers as DLA with no specific location, shows this occurs regularly in Hawaii. Nearly all Hawaiian units use both the local SMU (Combat Logistics Battalion 3) and DDPH. One method of circumventing the SMU and permitting a tactical unit to access DLA directly for DLA managed consumables is to use DOD's online, electronic mall (EMALL) requisition system. While possible, EMALL is only to be used when materiel is not available locally on garrison (Commandant of the Marine Corps 2014). Additionally, the SMU often has a much broader geographical range to its activities than merely local units. As discovered in the data, the Okinawan SMU, henceforth referred to as SMUO, has supported units which deploy to Australia, Philippines, and even Thailand. The overall number of Marines in the Pacific is not expected to increase by more than 2,500 and is expected to top out at around 31,000 total personnel (Fredlake and Randazzo-Matsel 2013). However, the required geographical footprint expands far beyond any increase in manning. The expense, distances, and proximity of different supply sources (SMU, DLA) encourage flexible sourcing solutions.

Figure 3 shows a typically conceived (and not uncommon) logistics structure. The tenet of this model is that each successive tier is positioned closer and closer to the end user or customer. The ability for all facilities in the first two tiers to serve the entire next subordinate tier maximizes the structural flexibility of the system (Kress 2002). Distances

between some Pacific nodes can be large enough to discount the likelihood those arcs will ever be used when other options are available. However, if stock-outs existed at the preferred, or closest, supply point, the many lines of communication, also known as edges or arcs, between each tier level would allow several other supply points to service the demand. For example, in Figure 3, if one unit at the operational level were unavailable or had no stock, the other operational level unit could service demand to any tactical level unit.
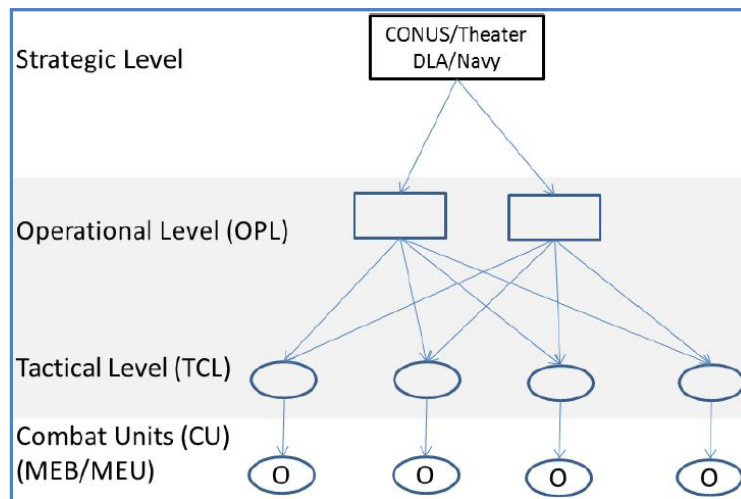
Figure 3.   Typical three-tier hierarchical logistical structure.

However, based on III MEF requisition data over nearly four years, the analysis supports depicting DLA as both a strategic and operational level supplier. When analyzing III MEF's data for individual National Stock Numbers (NSNs), DLA is often seen to be both a supplier to the SMUs and a direct supplier to tactical units. The "O," "G," "H," and "D" in Figure 4 represent the tactical level: Okinawa, Guam, Hawaii, and Darwin, Australia respectively. The blocks denoted "DDs" and "SMUs" represent multiple locations of each, but are shown as a single block to clearly indicate the relationships.
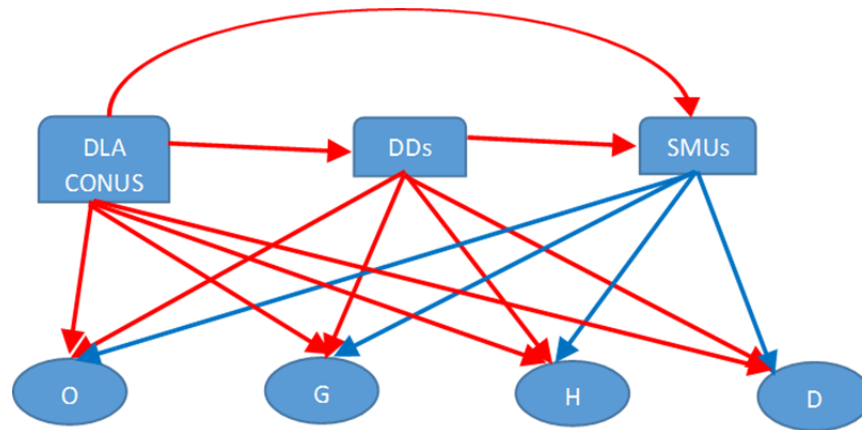
Figure 4.   USMC Pacific logistics structure for Class IX materiel.

A representative sample of items has been chosen for use in the MARPOM to speed calculation and analysis efforts. Specifically, we use the five most frequently requisitioned items by III MEF, noted in Table 1. This does not necessarily yield the five items with the most units requisitioned, just the most requisitions for a given item. A DLA Service Ticket, provided to the author after an online request for information (DLA Contact Center 2015), shows relatively large on-hand stock levels of these items, but not at every DD (see Table 1). It also reveals DDOJ stock levels nearly always significantly exceed DDYJ's. Despite DDYJ's much larger capacity, this seems plausible since DDYJ serves primarily Navy customers and DDOJ serves primarily Marines.

	DDPH	DDGM	DDOJ	DDYJ
Headlight (HL)	1100	100	393	29
1st Aid Kit (MK)	67	0	136	67
Grounding Rod (GR)	0	163	0	0
Diesel Kit (DK)	55	0	151	6
Wheel Chock (WC)	4	0	0	0

Table 1.   Pacific DLA Distribution site on-hand stock levels for five key items as of 23JUL2015 (from DLA Contact Center 2015).

Some of the DD sites have extremely limited stock on hand of the five items of interest, as of 23 JUL 2015. Every DD in theater does not necessarily stock every possible item. In a deterministic scenario, if the SMU has insufficient stock to satisfy demand, the fulfillment would come from whichever DD whose combined holding and transportation costs versus shortage costs is most beneficial. This would be similar to the tactical unit making the request directly to DLA, even though the request to DLA would originate through the SMU on behalf of the tactical unit.

The operational logistics system becomes quite simple with both DLA and SMU stock effectively working in tandem at the same tier when viewed from the tactical or combat unit's standpoint. In an annual time horizon, DLA resupply of SMUs can be assumed to occur as necessary throughout the period, but intermediate time steps in the supply chain's operations are disregarded. The intermediate steps need not be modeled explicitly as a precondition for the SMU to fulfill the tactical unit's demand. The SMU and DLA would merely be constrained by their capacity multiplied by the number of anticipated inventory turns during the time-step. DD inventory turns are assumed to be four, while SMUs are assumed to have a slightly quicker inventory turnover of value six. For example, if the annual shipments from a source node amounts to 1,000 cubic feet and the node's typical inventory turnover ratio was four, the storage capacity allotted to the shipped items is 250 cubic feet. Conversely, the inventory turnover is total shipments divided by average on-hand inventory. So, multiplying the apportioned storage by the inventory turns provides an expected constraint to shipments from a particular site. While simplistic, Figure 4 accurately depicts Class IX materiel supply chain and is the framework on which MARPOM is structured.

B.   COSTS

Typical monetary costs associated with any theater-wide logistics system include transportation related expenditures and holding and overhead costs within the "brick and mortar" portion of the system's infrastructure.

1. Transportation

Considering transportation first, the implications for an area as vast as Asia and the Pacific Ocean are not a trifling matter in either cost or coordination. As first realized during World War II, the challenge for Pacific operations is a tyranny of distance. Surface transport is cheap and can potentially move massive amounts of cargo, but it does so slowly. Air freight is fast, but has limited capacity and is very expensive. For a 20-foot intermodal shipping container equivalent (TEU) with 25,000 lbs. of materiel representing 1,360 cubic feet between Los Angeles and Honolulu, air freight for an equivalent weight and volume is approximately 30 times more expensive than shipping the TEU via commercial sea freight (World Freight Rates 2015).

One way to improve surface transport would be to utilize a disruptive technology, which can displace established concepts and lead to major transformations. Many have been considered over the years, hydrofoils, lightweight catamarans such as the Joint High Speed Vessels (JHSV), lighter-than-air airships (blimps or dirigibles), and a curious flying boat hybrid which uses the wing-in-ground (WIG) effect. They each have interesting attributes and could conceivably displace the more common transportation modes in some settings. The JHSV exists now with five vessels already in the Navy's register and another five being built. The WIG is one of the most interesting of the other potential technologies.

a. Joint High Speed Vessel

The JHSV (Figure 5) was originally intended to expedite intra-theater logistics. The Navy describes the JHSV as "Bridging the gap between low-speed sealift and high-speed airlift" at a speed nearly three times those of commercial vessels (U.S. Navy 2015). However, its operational range is only 1,200 nautical miles which limits the number of unrefueled port-to-port legs. With auxiliary fuel bladders, at-sea-refueling, or even port visits for refueling, its performance (shipping time) would still be much quicker than commercial shipping. As Navy owned, Military Sealift Command operated vessels, JHSVs have an annual operating cost of $26 million (Bacon 2014). A JHSV would make a 1,200 mile transit in a little over 24 hours, lifting 48, 20-foot containers modestly

loaded at 25,000 pounds each, with one day in-port at each end, resulting in a shipping cost of $4,450 per container. The only leg between Pacific locations of interest to this study which is less than the JHSV's 1,200 nautical mile limit is Okinawa, Japan to Manila, Philippines. The same 20-foot container would cost $1,100, using standard commercial ocean freight (World Freight Rates 2015). So, the JHSV looks to be three times as fast, but costs four times as much as regular sealift transportation. The Navy recently redesignated JHSVs to now become EPFs, which stands for expeditionary fast transport (Cavas 2015). This may be indicative of a return to its originally envisioned mission as an intra-theater logistics expediter.

Figure 5.   Cutaway view showing the JHSV's cargo carrying capacity
(from Defense Industry Daily Staff 2014).

b.   *Wing in Ground Effect Vehicles*

WIG effect vehicles (Figure 6), which utilize the extra lift found when an aircraft flies close to the ground or ocean's surface, have been around since about the 1960s. The Russians built the largest example, nicknamed the "Caspian Sea Monster," but the program lacked funding and foundered in the 1980s. Iran has produced a number of much smaller, single-engine, WIG craft for its military and was recently reported to have a

dual-engine version (Biggers 2015). China also has produced a WIG vehicle that has purportedly shuttled passengers between Hainan Island and the Paracel Islands (Want China Times 2014). The U.S. Army's Foreign Military Studies Office (FMSO) supported a paper that hypothesized the possibility of WIG craft large enough to transport 1,500 tons, 12,000 miles at 250 mph (Grau and Kipp 2000). Assuming such a large WIG's operating costs per flight hour were 50% more than a C-17 Globemaster, and that the actual volumetric capacity was half the FMSO paper's estimate, the WIG would still only be about 55% of a C-17's cost per cubic foot per mile. Calculated on the basis of a cost per pound per mile transported, the WIG's costs shrink even further to approximately 40% of a C-17's cost to transport. This calculation uses 18 as the C-17's load limit of type 463L, air cargo pallets if loaded to a maximum of 10,000 lbs. each, or a maximum volume of 485 cubic feet. These are rough estimates on a vehicle that does not yet exist, but the authors of the FMSO report deem it a promising force-deployment enhancement, which other countries are actively investigating.

Figure 6.   Artist's concept of a cargo version of a WIG craft studied
by Boeing (from Cole 2002).

2.   **Holding Costs**

Holding costs are based on estimated warehouse operating costs. While ostensibly quantifiable, its components are not easily obtained. Holding costs are typically measured as a percentage of the unit price, but, to be accurate, they should include amortized land

and building costs, insurance, security, equipment and personnel costs, inventory shrinkage, excess inventory disposal value, utilities, and take into account the time-value of money. However, if DOD Unified Facilities Code (UFC) area cost factors (ACF) for Guam, Australia, or Japan are applied to CONUS, facility specific, pricing factors developed by the U.S. Army Corps of Engineers, we can estimate the construction costs of warehouses (Department of Defense 2014). The estimate uses a cost of $2/sq. ft. for design, size ratios from the baseline data, and historical construction costs per sq. ft. A reasonable estimate of annual sustainment costs is $3 times the total square footage times the ACF (Fredlake and Randazzo-Matsel 2013). It is assumed this sustainment factor also applies to warehouses (as it does to maintenance facilities) and is considered to be conservative due to a warehouse's smaller equipment density. Amortizing the warehouse construction costs over a 30-year period, adding the sustainment costs, then dividing by the cubic feet of storage, we can derive an annual cost per cubic foot of storage for each location. This method has given us calculated holding costs per cubic foot, ranging from $0.79 to $1.35 with location being the primary cost driver. Another way to calculate the holding cost is to reference DLA's Distribution Depot fiscal year 2000/2001 biennial budget estimate which reports an average cost per cubic foot of covered storage as $0.83, which in today's dollars is approximately $1.15 using historical inflation rates (Defense Logistics Agency 2000). This provides a level of comfort and validity to the results of the UFC. The benefit of the UFC method is that it gives site specific cost factors, which, for example, makes Guam's storage more expensive than Hawaii's storage.

3. Penalties

The transport decisions of air vs. ocean, JHSVs vs. commercial freighters, and whether to build and operate a warehouse or SMU near the demand vs. accepting higher shipping costs all have to be considered and balanced against imposed penalties. Quantifying the economic impact or penalty of an item's non-availability is probably the most subjective aspect of modeling a logistics system. It is challenging to establish a monetary penalty associated with shortages in military logistics. Average customer wait time (ACWT) can be used as a proxy to evaluate an operational logistics system. It is not possible to model ACWT since the extent to which every function and facility impacts

ACWT is not known from the data. In MARPOM, factors are applied to shortfalls in high and low-priority demand based on an item's cost, with unmet high-priority demand receiving a penalty ten times that of the low-priority penalty. This factor has been varied to investigate MARPOM's sensitivity.

C.   DATA

CNA provided a dataset which had been originally used to support the abovementioned 2013 study (Fredlake and Randazzo-Matsel 2013). The dataset is comprised entirely of Repairable Issue Point (RIP) items, which are typically large, expensive items available to a unit through direct exchange. In other words, the unit will not receive a generator set, for instance, until it turns-in its non-operative generator set. If no replacement item is available at the time of turn-in, a requisition will be placed through SMU with the carcass routed to the responsible repair activity. It is more cost-effective for these RIP items to be repaired than to be considered a consumable item, making the turn-in necessary.

In general, per USMC policy contained in Marine Corps Order P4400.151B, RIPs manage Secondary Repairables, which consist of both Depot Level Repairables (DLRs) and certain Field Level Repairables. The goal is always to effect repair at the lowest possible maintenance level. If the repair of an item requires skills, personnel, or special tools beyond what is available below a fifth echelon maintenance activity or depot, then the item is classified as a DLR. According to Marine Corps Order P4790.1, all maintenance echelons below the fifth echelon are considered field maintenance activities, all the way down to the individual user or first echelon. The RIP acts as an intermediary between the user and these repair entities. The RIP's purpose is to maintain an inventory of these repairable items available for direct exchange in accordance with their catalog of supported items. As this does not reflect the majority of Class IX items and exhibits a two-way flow, it has not been modeled in this thesis.

However, the dataset contains 95% of the necessary data fields which, if populated with general Class IX requisitions, could establish a baseline or status quo for MARPOM's recommendations and comparisons. Contact was made with a recent NPS

graduate, Major Bert Cruz, Deputy Director Studies and Analysis Division, Marine Corps Logistics Command, Logistics Capability Center, and the extent and intent of the thesis was explained. He acknowledged his office was fully capable of extracting the data necessary. After a second conference call between him and James Watts, also of Major Cruz's division, the requisite data fields were submitted with the understanding that Class IX non-RIP items for III MEF would be pulled from multiple systems. The data received as a result of this coordination became the basis for the analysis contained herein.

A characterization of the data shows that several types of repair parts dominate the Marines' demand. Figure 7 and Figure 8 show the dominant Federal Supply Groups (FSGs) based on the number of requisitions and the total requisitioned quantities, respectively. The first four digits of an NSN will provide a corresponding detailed descriptor of the item type. For example, an NSN which begins with 2050 is for "Buoys." The first two digits (20) gives a general FSG, such as "Ship and Marine Equipment" from our previous example.
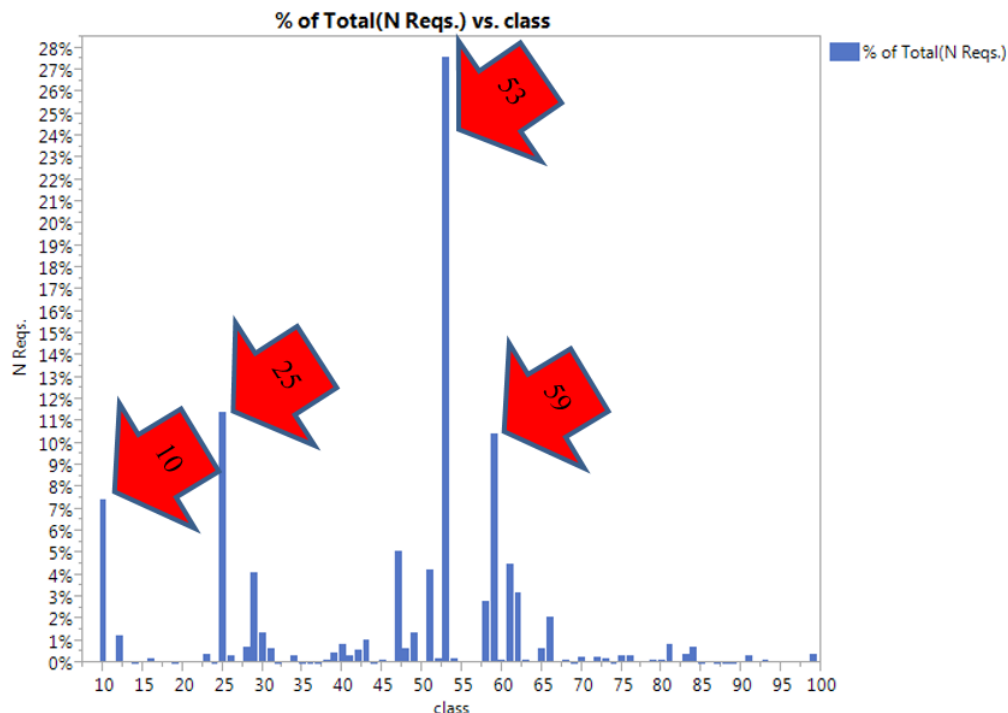

Figure 7.   Requisitions by Federal Supply Group (FSG) as a % of all III MEF Requisitions with top four FSGs being 53, 25, 59, and 10, respectively.
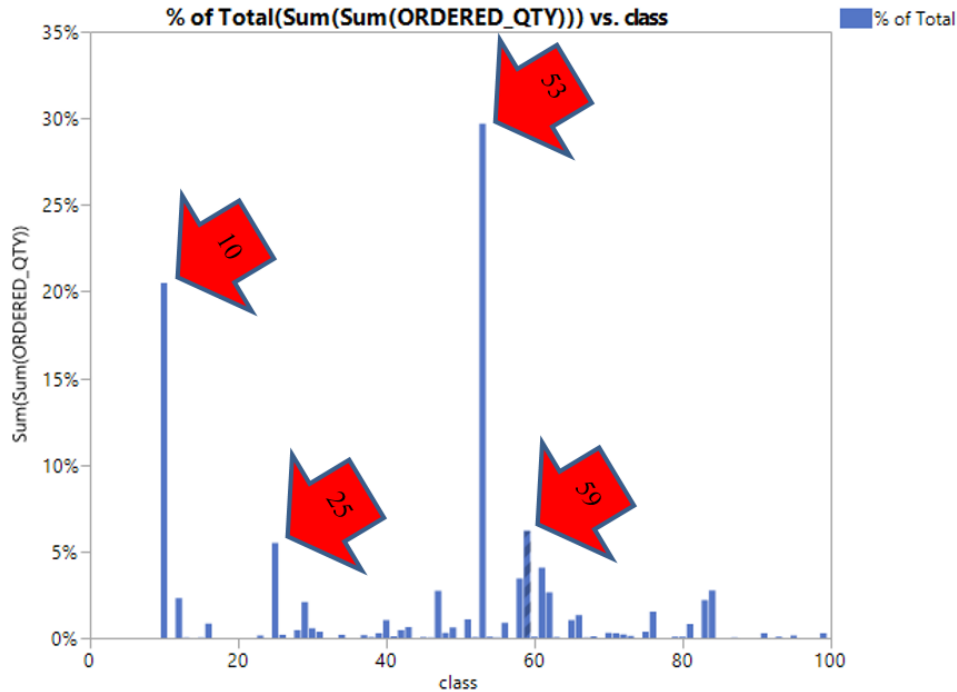
Figure 8.   Top four FSGs with highest quantities ordered are identical to those with greatest number of requisitions (Figure 7).

The four largest FSGs in terms of the number of requisitions are Class 10–Weapons (7.4%), 25–Vehicular Components (11.4%), 53–Hardware & Abrasives (27.6%), and 59–Electrical and Electronic Equipment Components (10.4%). With only slightly different proportions, the same FSGs remain the top four FSGs when ordered quantities are considered. Two of the five most frequently requisitioned items fall within one of these top four FSGs.

Using the raw data set, Figure 9 shows the two largest suppliers are DLA and the SMU in Okinawa. The suppliers in Figure 9 and the requisitioners in Figure 10 are listed by Department of Defense Activity Address Code (DODAAC). The information in the provided data does not allow a differentiation between CONUS DLA-provided materiel and Pacific DD-provided materiel. Since the SMUs are restocked from DLA sources, most of the materiel shipped by DLA in Figure 9 represents the combined demand generated by the SMUs as shown in Figure 10. However, DLA's total from Figure 9 exceeds the combined requirements of SMUO and the Hawaiian SMU (SMUH), which would indicate DLA supplies some tactical units directly.
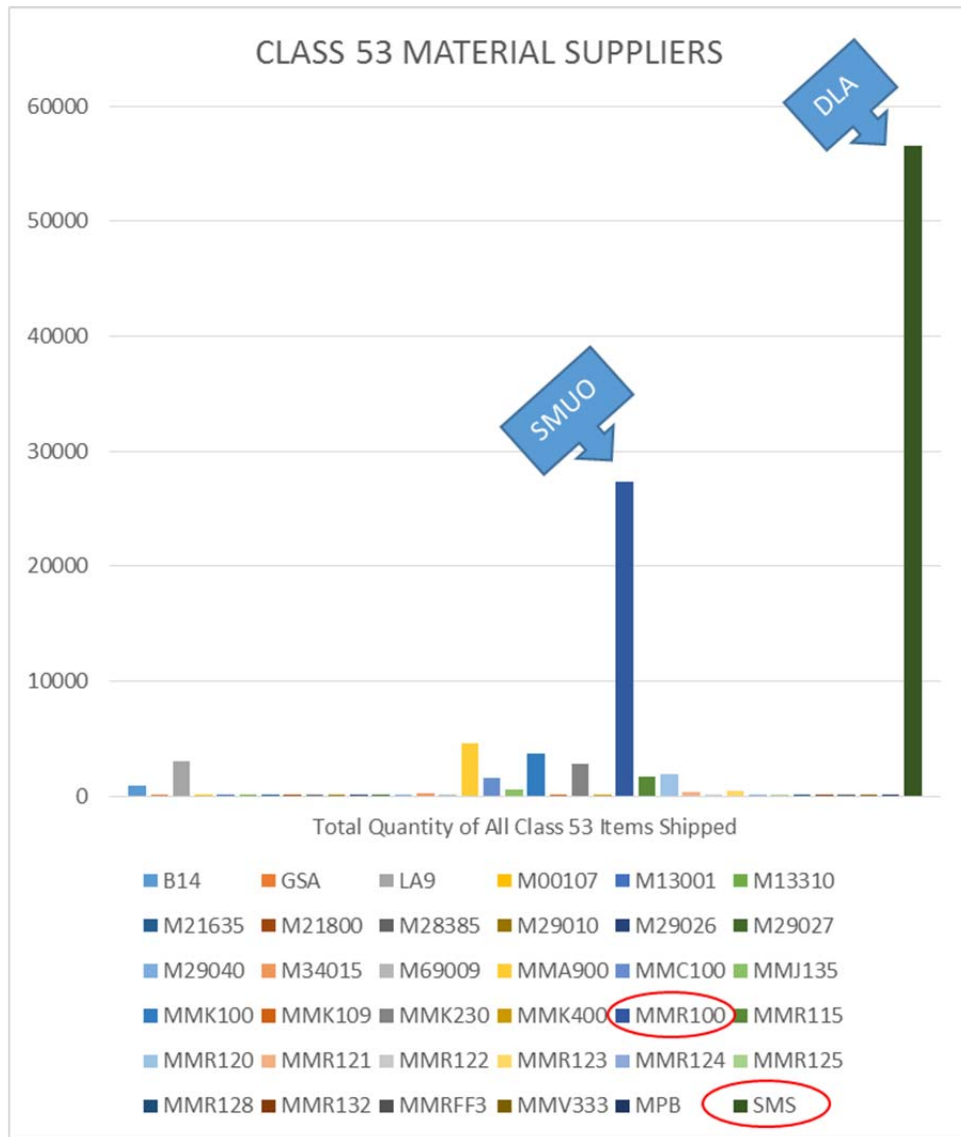
Figure 9.   Sources of Class 53 materiel to satisfy requisitions,
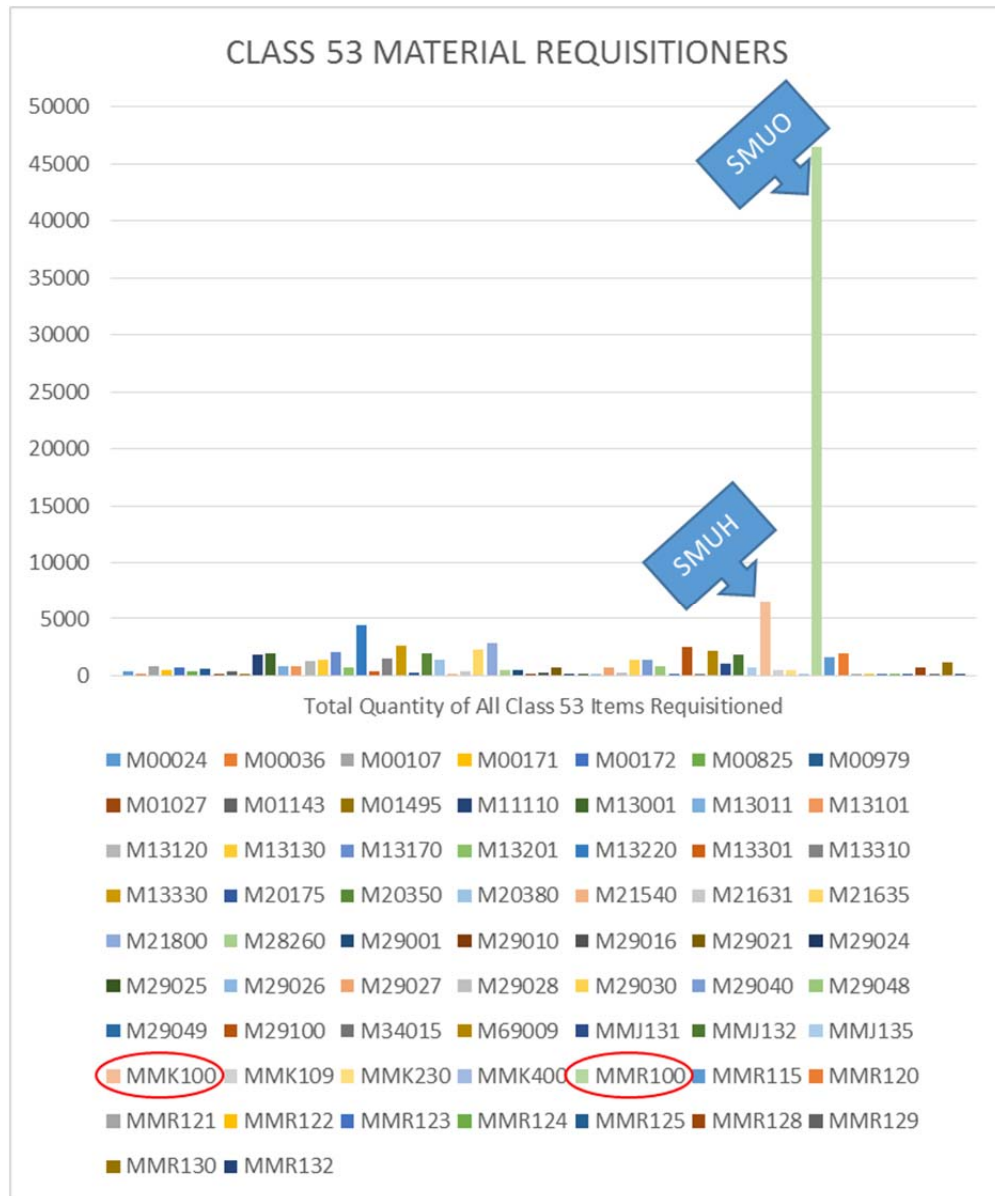with top two highlighted.

Figure 10. Consumers who requisitioned Class 53 materiel,
with top two highlighted.

1.   Inventory Structure

DLA figures prominently in any study of Class IX, repair parts logistics. In fact, all five of the most frequently requisitioned Class IX items by 3rd Marine Expeditionary Force, or III MEF, are DLA-managed items. As the network analysis of each item's requisitions shows, the flexibility of the support reflects a combination of DLA's and the SMU's inventory policy for that item. The five items range from a shelf-life managed

item, which is primarily stocked by DLA (1st Aid Kit), to an item which can be sourced from the SMU, several DD sites (DDGM, DDOJ, DDYJ, DDPH, etc.), or even reaching back to DLA CONUS. Then, there are others which are solely stocked at an SMU, but not at a DD, or vice versa. These are all scenarios to be evaluated with varying support entity availability and proximity to the demand source.

The following series of figures, Figures 11–15, depict a network representation of the materiel flow for the five most frequently requisitioned items in III MEF for the approximate time period between May 2013 and September 2014. This data set is a compilation of that which was provided by Maj. Cruz's office and a DLA Service Ticket requesting a listing of DD locations currently stocking these items, as found in Table 1. This provides an assumed origin for most of the DLA fulfilled requisitions. The arcs have small arrowheads pointing to the originator of the requisition or demand generator. The non-labeled nodes, or arc termination points, are tactical units. Locations, such as Philippines and Guam, represent deployed units.
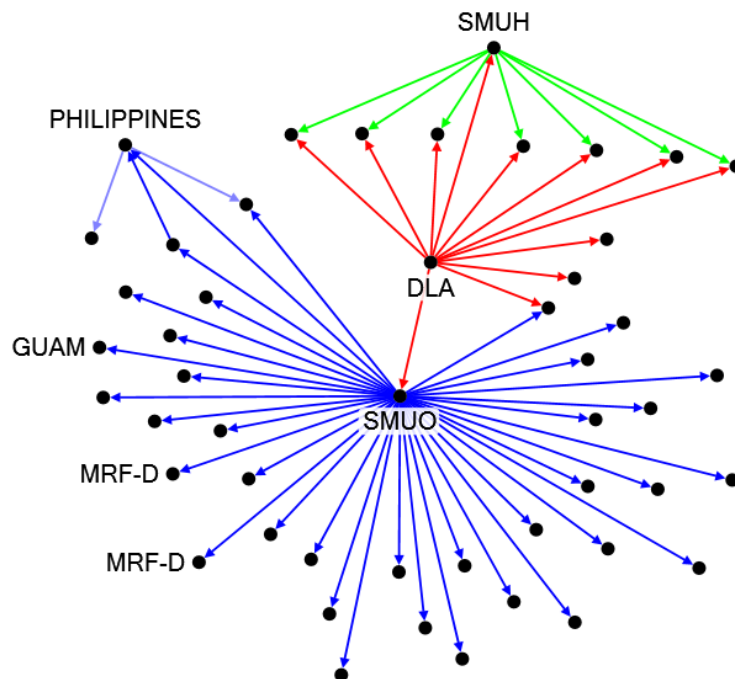

Figure 11.   NSN 6240–00–966–3831: Truck headlight. SMUO supports Okinawan units and units deployed to Philippines, Guam, and Australia, while Hawaiian units receive direct DLA and SMUH support.
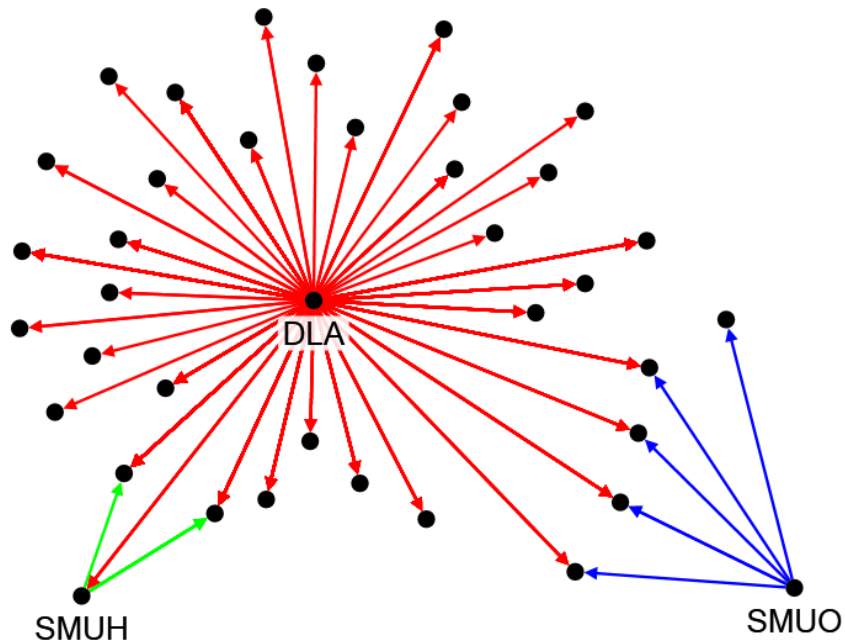
28

Figure 12.   NSN 6545–00–922–1200: Vehicle First Aid kit is a shelf-life item
primarily stocked by DLA with SMUO and SMUH
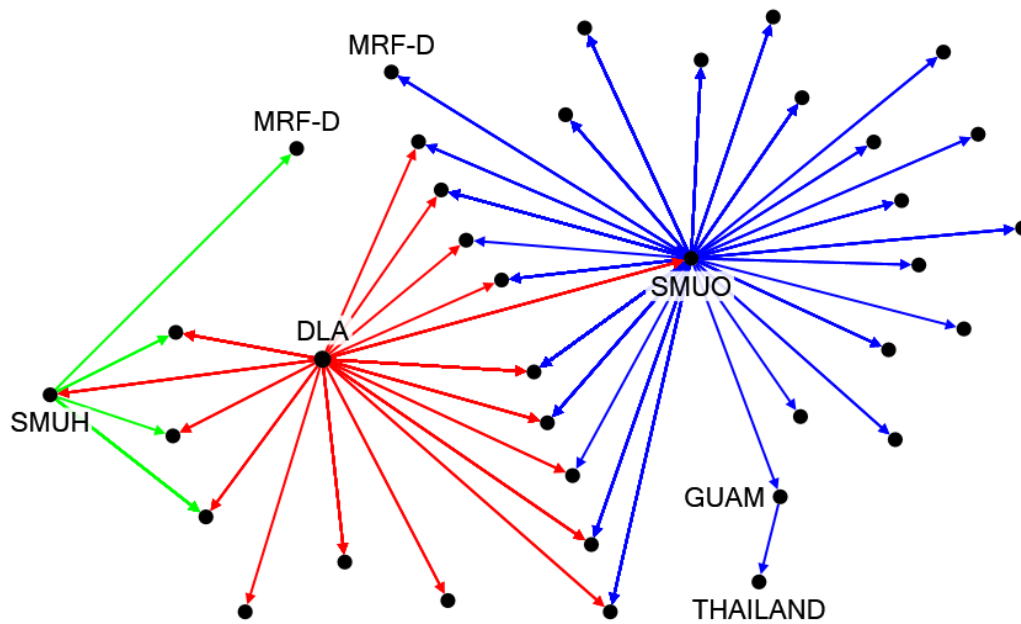supporting few units.

Figure 13.   NSN 5975–00–878–3791: Grounding rod stocked by SMUO,
SMUH, and DDGM (Guam) with mixed sole support in Hawaii.

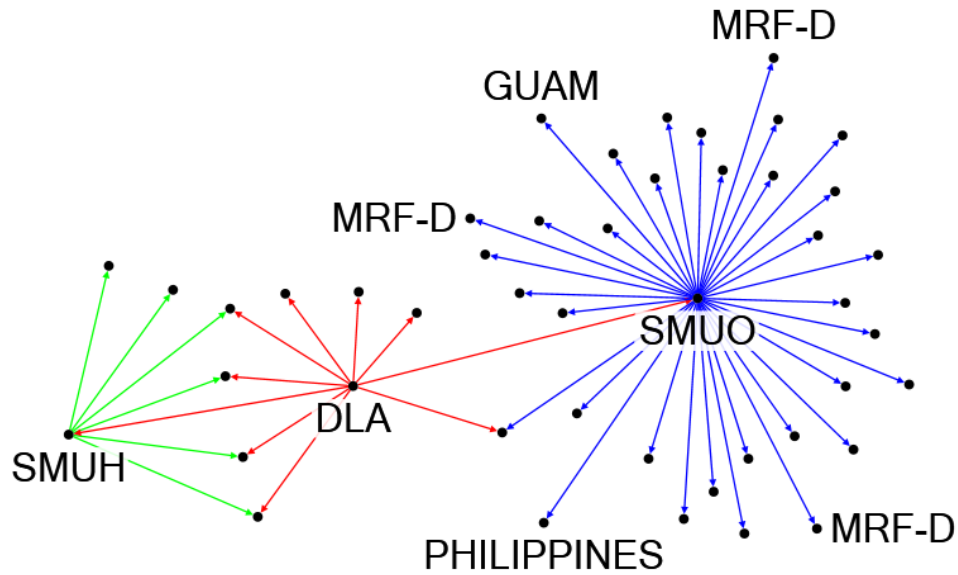Figure 14.   NSN 2815–01–492–5709: Parts Kit, Diesel Engine showing a
similar requisition fulfillment sourcing pattern as seen in Figure 11.
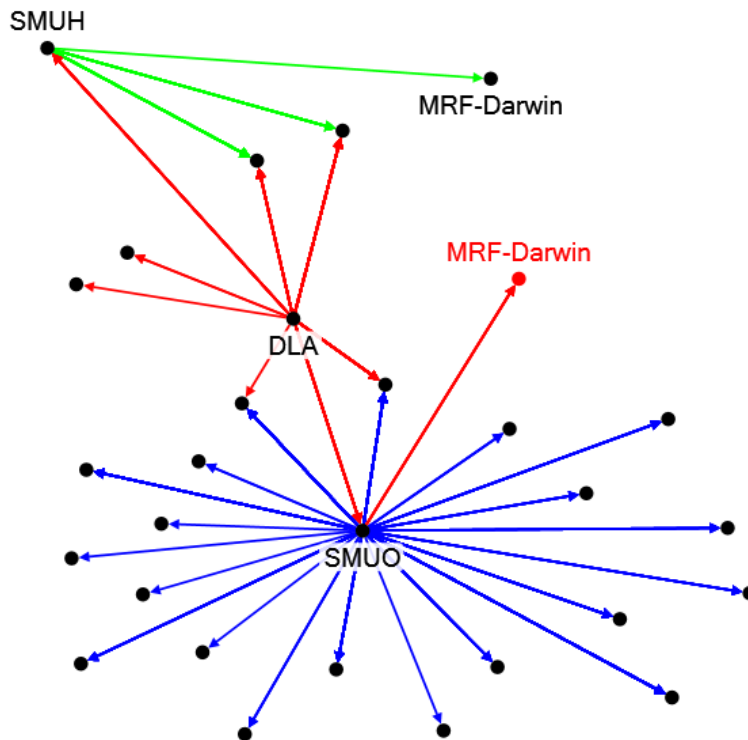MRF-D used three Unit Identification Codes and is shown thrice.

Figure 15.   NSN 2540–01–165–6136: Wheel Chock network showing a similar
pattern to Figure 11 or Figure 13 and dual support for MRF-Darwin.
MRF-D used two different Unit Identification Codes and is shown twice.

Although not specifically included in MARPOM, the DD can operate on either wholesale or retail basis. As wholesale, the DD's stock is available to all services and initial acquisition and holding costs are shouldered by DLA. This can lead to stockouts, even with low Marine demand, because the demand from other services could exceed stock on-hand at the DD or even DLA CONUS. If the Marines provide funds, DLA can reserve stock for Marine use only in the retail model. This creates a large upfront cost, but DDs will effectively act as the SMU for that item, performing SMU receipt, stow, and issue functions.

Stocking policy consisting of safety stock, reorder quantity and other determinants would be specified by USMC, but implemented by DLA. This could greatly reduce the storage requirements at the SMU or each unit's organic storage, depending on how widely this technique is adopted. Manpower requirements could also be impacted, although it may just be a transference of man-hours from the Marines to DLA. Taken to the extreme, it could obviate additional SMUs where DLA already has a presence.

2. Inventory Flow

The most requisitioned item by III MEF is a truck headlight (NSN 6240009663831). JMP 12 (SAS Institute Inc. 2015), a statistical analysis program developed by the JMP business unit of SAS Institute, has been used to display the relationship between time to fulfillment and source vs. end user, as shown in Figure 16. The supply source (SHIP_FROM_ORG) is displayed on the left vertical axis and the demand node (SHIP_TO_ORG) is on the bottom horizontal axis with five time periods for the requisition creation date (REQUISITION_DATE) across the top horizontal axis and materiel receipt date (DATE_CLOSED) with five other periods on the right vertical axis.
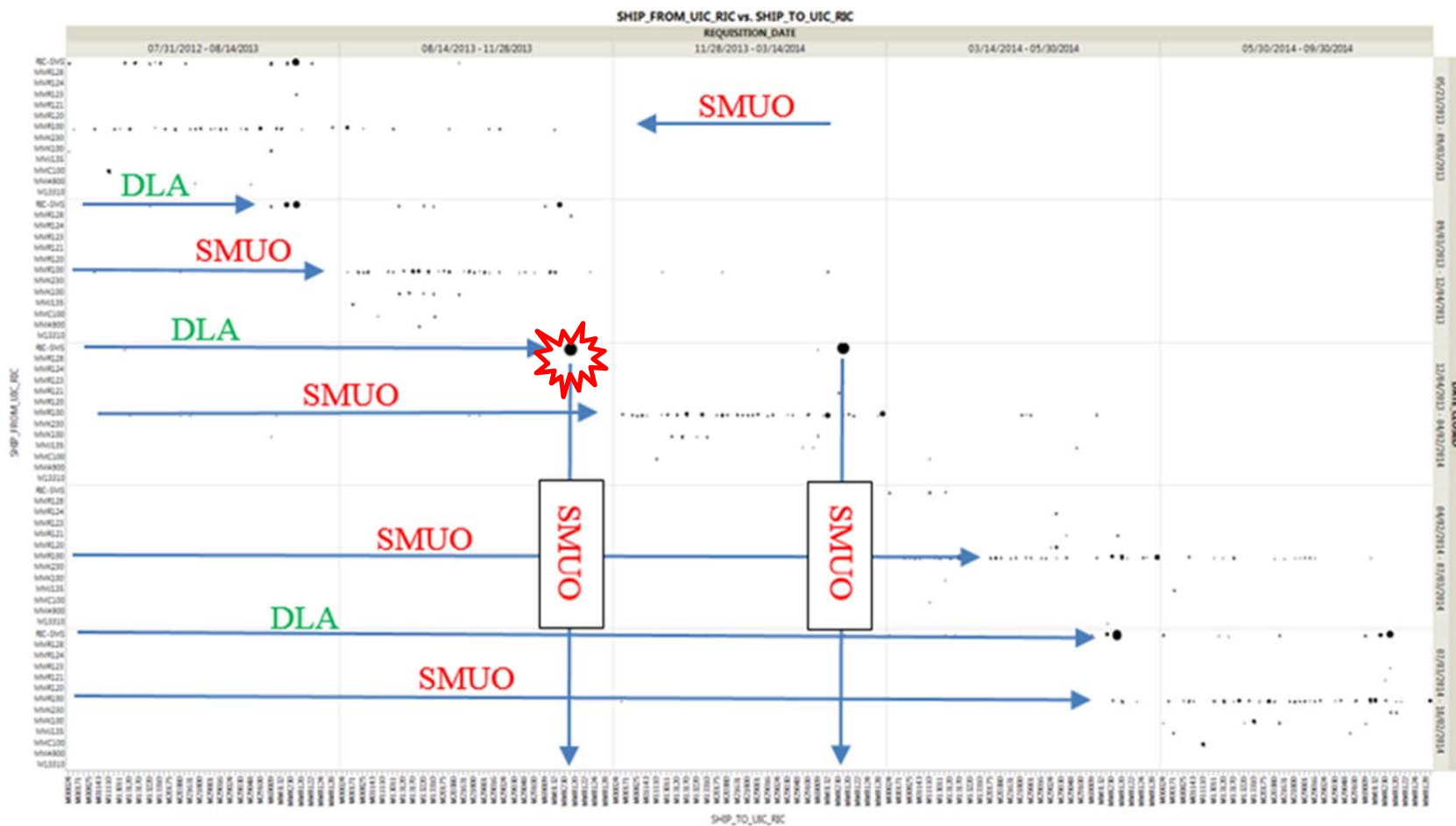
Figure 16. NSN 6240–00–966–3831: Horizontal patterns represent primarily SMU requisition fulfillment to supported units over time and large dots indicate DLA fulfilling SMU stock replenishment requisitions.

Figure 16 combines 25 plots in one to show one item's primary requisitioners and suppliers from July 2012 to November 2014. Each block shows a requisition was placed by someone (bottom horizontal axis) within a certain time period (top horizontal axis). That same requisition was fulfilled by someone else (left vertical axis) within another time period (right vertical axis). The total time period spanning order placement is different from the total period which includes order fulfillment. JMP chooses five sub-periods each representing 20% of the requisitions by submission date and by fulfillment date for the top horizontal axis and the right vertical axis, respectively. So, multiple fulfillment time periods, or blocks, will apply to a single submission time period. This represents the spread of ACWTs experienced by units submitting requisitions during a particular span of time. This is seen in Figure 16 as the column of five blocks arranged under a requisition date time period heading. The size of the dots is proportional to the quantity ordered with each requisition. The largest displayed dots were fulfilled by DLA with a Routing Identifier Code of SMS, which means the item was shipped by a non-specific DLA facility, but it is assumed to be a Pacific DD. It could have been a CONUS facility or DDYJ, for example, but we have not been able to tell given the granularity of the available data.

For example, if we consider the highlighted requisition in Figure 16, it was placed by SMUO somewhere within the time block of 14AUG2013 and 26NOV2013. It was fulfilled by DLA at some point in the date range of 4DEC2013 and 2APR2014. The dot's size indicates a large quantity requisition.

Most of the DLA shipments are destined for 3rd Supply Battalion CLR-35 3rd MLG, indicated by the DODAAC MMR100 in Okinawa, Japan or MMK100 in Kaneohe, Hawaii. This also shows that MMR100 is fulfilling the vast majority of requisitions to very disparate end users. Another conclusion which can be obtained from the graph is that most requisitions are filled quickest through MMR100 and DLA's ACWT is typically a few months, as shown in Figure 17 and Figure 18. This temporal observation could justify the existence of a local SMU, whose stock acts as a buffer against long lead times from DLA, or be used as an argument to engage DLA in a retail arrangement.
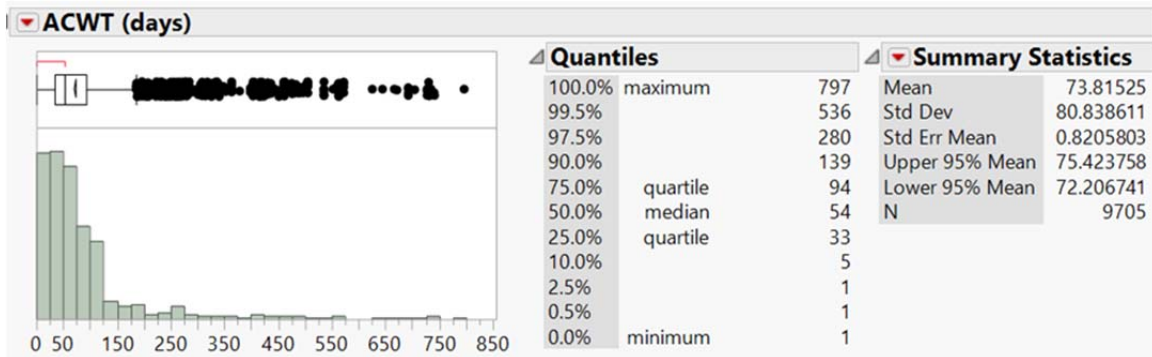
Figure 17.   ACWT for DLA filled requisitions from SMUO.
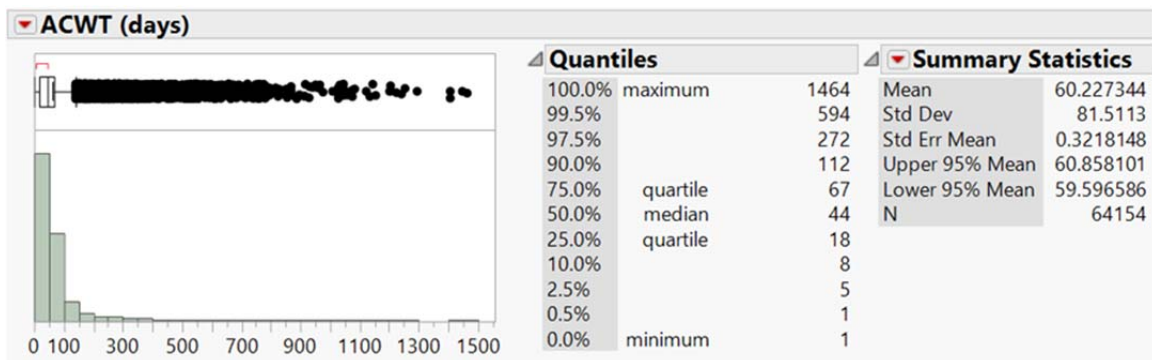
Figure 18.   ACWT for all DLA filled requisitions from both SMUs and tactical units.

Figure 19 and Figure 20 depict the customer wait times (CWT) using violin plots with superimposed interquartile box plots to emphasize the range of CWT. The violin plot is a rotated histogram of the number of requisitions at a given CWT level. Interestingly, there was no DLA support of any units in Guam within the dataset. All support provided to Guam came from SMUO in Figure 20, which could be attributed to DDGM's size.
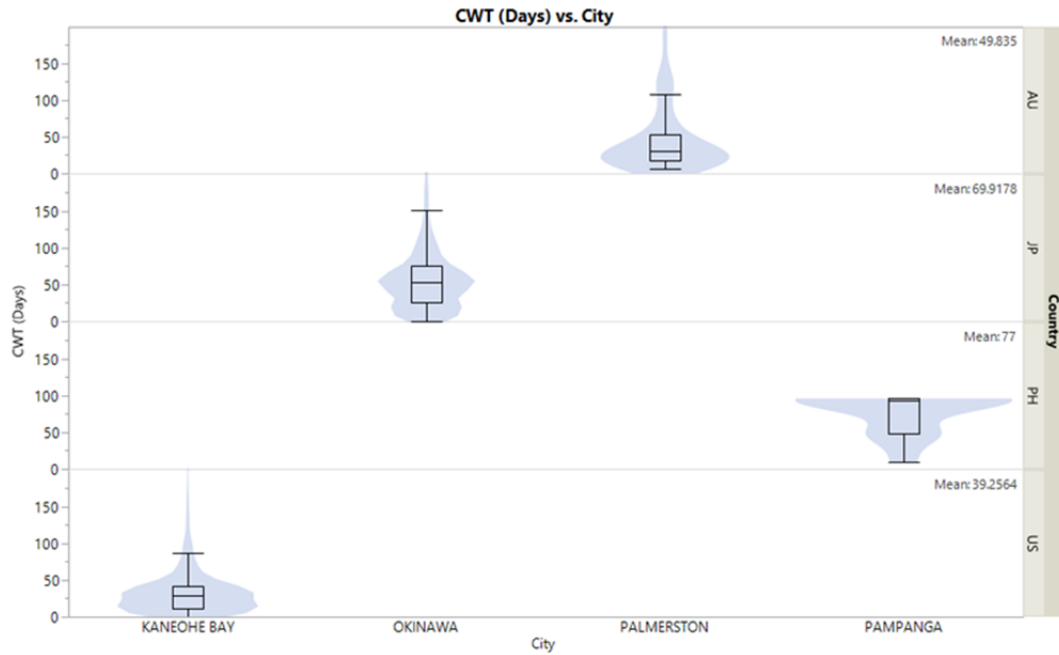
Figure 19.   Violin/Box Plot of DLA CWT at different customer locations.
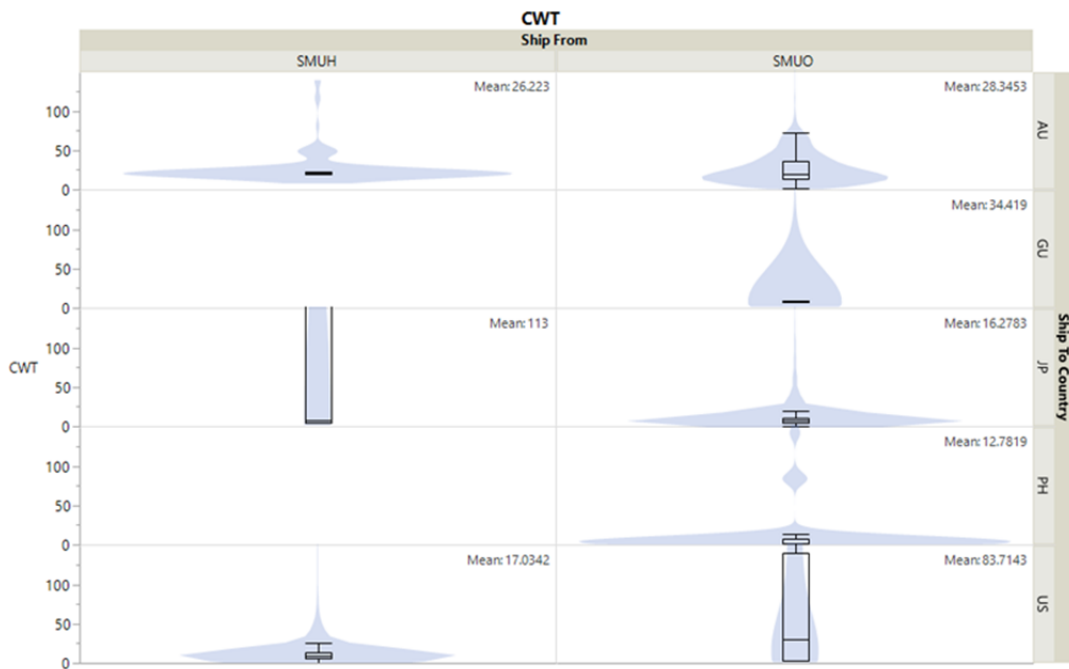
Figure 20.   Violin/Box Plot of SMUO and SMUH CWT at different locations.

Although there were very few requisitions from Hawaii fulfilled by SMUO and from Okinawa fulfilled by SMUH, both situations show this to be the least efficient SMU support offered in terms of mean CWT, or ACWT, annotated in Figure 20. When the Ship_To_Country in Figure 20 is labeled as "U.S.," it only represents Hawaii. Of note, when both SMUs support MRF-D in Australia and their own local constituencies, they have similar ACWTs, indicating a consistency to SMU operations.

IV. SUPPLY CHAIN OPTIMIZATION

A. ASSUMPTIONS

The purpose of this chapter is to expand on some of the necessary assumptions used in MARPOM and to present its mathematical formulation. First, the reader is cautioned that most of the data used to establish costs and capacities for transportation modes and facilities, demand distribution, penalty magnitudes, etc., have been estimated by the author, but without sufficient information to make them a reliable projection. As such, results derived from MARPOM with the given data constitute only a proof of concept, i.e., a starting point from which to investigate relationships between different logistical network factors. MARPOM's solutions may not always be feasible in reality. So, for example, knowing the second-best location to expand can be just as important as knowing the optimal location.

The structural basis for MARPOM was shown earlier in Figure 4. A deterministic approach rather than stochastic was determined as best suited for building a baseline model describing the fundamental properties of the logistical deployment in the Pacific. However, troop placements, warehouse sizes, transportation costs, operational costs, and even demand, barring catastrophes or war, are reasonably static over longer time periods, befitting an initial deterministic approach. We choose one year as the logical time period for data input to the model. For example, demand is annual demand; holding costs use annual warehouse operational costs; transportation limits are based on annual transportation frequency between nodes; transport costs are derived from annual operating costs.

In order to determine a warehouse's capacity devoted to certain USMC materiel, we use a conversion parameter, r (see notation below) that reflects an inventory's turnover period at a certain warehouse. For example, if DDOJ maintains a stock level of 25 units of a particular item, but ships 100 units annually, their annual inventory turnover ratio would be four. The warehouse volume for this item only needs to be sufficient for

the 25 units, not the entire annual demand of 100 units. This effect is explicitly incorporated in MARPOM using estimated values for turnover ratios.

No starting inventory is assumed, because part of MARPOM's intent is to determine an optimal apportioned inventory volume at each DD or SMU in steady-state conditions. Therefore, those initial quantities become irrelevant. MARPOM finds the most economical source for the mixed demand and apportions it at minimum cost, but only to the extent to which each site's capacity and transportation constraints allow. Here, cost includes warehouse holding costs and transportation costs with an associated penalty for unmet demand.

Both high and low-priority demands are determined with a single input factor applied to all items and locations, indicating the percentage of high-priority requisitions. The designation serves to determine the transport mode selected: high-priority items are only shipped by air and low-priority shipped by sea. Sea and air modes have capacity limits on each leg or edge of the transport network. These limits are also input parameters. Since no data regarding actual transportation capacities could be obtained, it was decided to make these capacities sufficiently large so that shipments have not been restricted by arbitrary limits. MARPOM's formulation includes this constraint, so, if actual capacities become available, they can be enforced in the model.

Holding costs per cubic foot are partially derived from facility constructions costs amortized over 30 years. The cost to build and operate DLA sites are based on the UFC guidelines with site specific construction factors (Programming Admin. and Execution System 2015), which assumes 26 foot, high-bay buildings. MARPOM accepts overall DD site volume as direct inputs, but the SMU's volume is that which is suggested by the UFC using the number of troops which the SMU supports. Since the size of the SMUs in Okinawa and Kaneohe Bay could not be obtained, MARPOM uses the warehouse guidelines based on number of troops served, which is contained in Office of the Chief of Naval Operations Instruction 4441.12D, Retail Support of Naval Activities and Operating Forces. The size of the SMU and consequently its holding costs are calculated based on the number of troops in each location. If the number of troops is increased or reduced at a location, the SMUs' size and holding costs will change appropriately. The SMU is

assumed to be a 10 foot high storage space. The usable volume within these buildings dedicated to storing the items considered in this thesis is obviously less than the total capacity. Due to a DD's high-bay operation and the need to get high lift equipment between shelving, an 80% utilization of the total volume is assumed. The SMU is presumed to have slightly higher amount, 85% of total volume, used to house materiel. An additional capacity limit is imposed using a factor of 0.2% to reflect that the five items analyzed only represent a fraction of the expected volume necessary to support USMC demand. In the absence of complete inventory lists, stocking levels, and the associated item volumes, our 0.2% factor is an assumption without any quantifiable basis. The estimates certainly could be improved with full knowledge of parts stocked and details on SMU and DD facilities.

B. THE MARINE'S ALLOCATION OF RESOURCES PACIFIC OPTIMIZATION MODEL (MARPOM)

To create a useful decision support tool to help the distributed laydown process match the proposed USMC troop deployments, MARPOM focuses on the SMU and DD capacity balance. Demand is found in five locales at the tactical level (shortened names used for brevity in some descriptions and tables): Okinawa (O), Guam (G), Hawaii (H), Darwin, Australia (D), and the Philippines (P). Demand at the tactical level is determined by the ratio of troops in a location to the total III MEF troops in the five locations. This ratio is multiplied by the total annual demand of an item by III MEF to determine the yearly demand for that item in a certain location. If demand from the USMC units deployed to an area is known, then these calculated values can be overridden with the actual data.

This demand can be met by the intermediate level SMUs or DDs, but the DDs must ultimately support the SMUs to the extent to which the SMUs support the tactical units. The optimized capacity for item m at DD i designated for SMU i' is represented by MARPOM's decision variable $K_{ii'm}$. While the DDs are capable of direct support to the tactical level or combat units, it was not possible to determine from available information to what extent the USMC utilizes this type of support, if at all.

An ACWT analysis of the USMC Logistics Capability Center's dataset shows SMUs have a clear advantage in response time over DDs. Since the premise for a SMU is to reduce wait times and increase availability, this result stands to reason. MARPOM's penalty factor, gdd_{ijp}, monetizes, in \$/cubic feet, the increased ACWT experienced by customer *j* whose materiel is DLA sourced through supply node *i*, effectively introducing a penalty for DD materiel. This drives the model to favor stock at SMUs over DDs, even if co-located. The advantage is graphically shown in Figure 21, where ACWT is compared for the five analyzed items and for all of III MEF's requisitions. DLA's ACWT is almost four times as long as that experienced at SMUs.
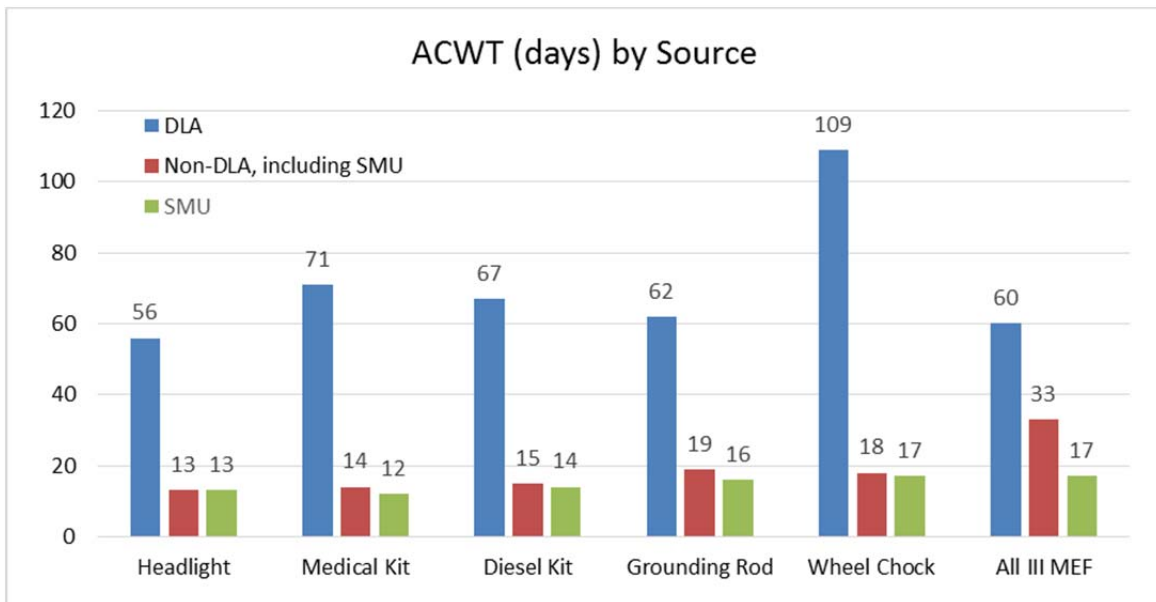

Figure 21.   Showing the greater responsiveness (shorter ACWT) of SMUs compared to DLA.

DDs are co-located with both of the existing III MEF SMUs and would, at first, seem to be duplicitous capabilities. Once ACWT is determined for DD vs. SMU, the speed of fulfillment by SMUs becomes the obvious answer for their existence.

MARPOM can handle all current SMUs and has the capability to include additional SMUs at troop deployment locations where they do not yet exist. The same is true for DDs. So, MARPOM can analyze any combination of SMUs and DDs in the five

troop deployment locales. For example, it could provide capacity recommendations for USMC materiel at a potential future DD in the Philippines and a SMU in Australia, or vice versa, or a DD and SMU in both locations. The demand is represented by the five most frequently requisitioned items by III MEF, as described above in Table 1: headlight (HL), medical kit (MK), grounding rod (GR), diesel kit (DK), and wheel chocks (WC), which are abbreviated as shown in both the model and the results for convenience. However, MARPOM could be expanded to include many more III MEF demand items.

MARPOM seeks values for two key sets of decision variables. The first, X_{ijmp}, includes shipped amount of item m by a certain transport method p from supply node (i.e. DD or SMU) i to demand node j. The second includes the designated capacities for the various items in the various supply locations to accommodate USMC demand. At both SMU and DD sites these variables are represented by A_{im}, where i is the supply node and m is the particular type of item. DD sites also include additional capacity, $K_{ii'm}$, to account for SMU resupply, as described above. Then the optimization is accomplished through minimizing an objective function comprised of three major terms (see detailed description in subsection 5 below).

MARPOM accounts for a number of constraints representing physical and logical restrictions. For example, shipments from a node cannot exceed the node's USMC inventory capacity. To give the model flexibility, the possibility of unmet demand is included but sufficiently penalized. This discourages MARPOM from choosing such a solution if a feasible one (that meets all the demand) exists, but establishes tradeoffs otherwise. As discussed later, if this penalty is small, MARPOM may choose to leave unmet demand in lieu of incurring the stocking and transportation costs of satisfying it.

All of the supporting time-distance calculations, transportation cost estimations, warehouse sizing, and holding cost estimations are managed in an Excel worksheet specifically designed for this research. It is used to generate the comma separated value data files that feed the General Algebraic Modeling System (GAMS) CPLEX optimization solver (GAMS Development Corp. 2015).

1.   **Sets and subsets**

$i \in I$ Supply nodes (DDPH, DDGM, DDOJ, DDYJ, DDPI, DDAU, SMUO, SMUG, SMUH, SMUP, SMUD)

$I^{DD} \subset I$ Subset of DD supply nodes (DDPH, DDGM, DDOJ, DDYJ, DDPI, DDAU)

$I^{SMU} \subset I$ Subset of SMU supply nodes (SMUO, SMUG, SMUH, SMUP, SMUD)

$j \in J$ Demand nodes (aggregated tactical units) (O, G, H, D, P)

$m \in M$ Items or commodities (HL, MK, GR, DK, WC)

$p \in P$ Requisition priority (Hi, Lo)

2.   **Parameters (and units)**

b_{ijp} Transportation capacity limit of shipments from supply node i to unit j via priority p transport method. (cubic feet)

c_i Total storage capacity at supply node i. (cubic feet)

d_{jmp} Demand at unit j of item m of priority p. (unit of issue)

f_{mp} Penalty multiplier of unmet demand for item m by priority p. ($/unit of issue)

g_{ijp} Transportation cost from supply node i to unit j via priority p transport method. ($/cubic foot)

gdd_{ijp} Penalty cost from supply node i to unit j via priority p transport method associated with portion of DLA ACWT which exceeds SMU ACWT. (It penalizes DLA requisition fulfillment delay compared to SMU, using ACWT as a basis of comparison). ($/cubic foot)

h_i Holding cost at supply node i. ($/cubic foot)

r_i Inventory turnover ratio for supply node i. Calculated as the amount of total annual shipments divided by the average inventory. (unitless)

$e_{ii'}$ Transportation and holding costs associated with DD resupply shipments to SMUs. ($/cubic feet)

v_m Volume of item m. (cubic feet/unit of issue)

3. Decision Variables (and units)

X_{ijmp} Amount of item m shipped by priority p transport method from supply node i to unit j. (unit of issue)

A_{im} Apportioned capacity at supply nodes i to meet demand for item m. (cubic feet)

$K_{ii'm}$ Apportioned capacity at DD supply nodes i to meet SMU i' demand for item m. (cubic feet)

q Value of the penalty for all unmet demand. ($)

Z Objective function value. ($)

4. Constraints

MARPOM incorporates the following constraints:

— The apportioned capacity at SMU i for item m is equal to the quantity shipped from SMU i times the volume of item m divided by the inventory turns:

$$A_{im} = \sum_{j}\sum_{p} \frac{v_m X_{ijmp}}{r_i} , \quad \forall\, i,m \,\big|\, i \in I^{SMU} \tag{1}$$

— The apportioned capacity at DD i for item m is similar to equation (1), but the DDs must also have the capacity to supply the SMUs with an amount equivalent to the total SMU shipped amounts:

$$A_{im} = \sum_{j}\sum_{p} \frac{v_m X_{ijmp}}{r_i} + \sum_{i' \in I^{SMU}} K_{ii'm}, \quad \forall i,m \big| i \in I^{DD} \tag{2}$$

— Define the second term of equation (2), or the additional DD capacity, based on the SMUs' shipped quantities, which must be carried at the DLA depots in order to resupply the SMU:

$$\sum_{i \in I^{DD}} K_{ii'm} r_i = \sum_{j}\sum_{p} X_{i'jmp} v_m, \quad \forall i',m \big| i' \in I^{SMU} \tag{3}$$

— The total apportioned capacity at supply node i for all items must not exceed its total capacity:

$$\sum_{m} A_{im} \le c_i \ , \quad \forall i \tag{4}$$

— The amount of product shipped along a given transportation leg between supply nodes i and demand nodes j must not exceed the capacity of transportation modes (sea and air combined), on that i-j leg.

$$\sum_{m} v_m X_{ijmp} \le b_{ijp} \ , \forall i,j,p \tag{5}$$

— Ensure supply does not exceed demand:

$$\sum_{i} X_{ijmp} \le d_{jmp} \ , \forall j,m,p \tag{6}$$

— Account for unmet demand and its cost:

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$$q = \sum_{j} \sum_{m} \sum_{p} \left[f_{mp} (d_{jmp} - \sum_{i} X_{ijmp}) \right] \qquad (7)$$

Note: The parameter f_{mp} is a scaled penalty value measured in U.S. dollars per unit of issue and based on a multiplier of the item's cost. For example, wheel chocks are $9.90 each and the chosen Hi-priority penalty multiplier is 100. Then each unit of unmet Hi-priority demand for wheel chocks is penalized $990. Its implementation assumes that Hi-priority unmet demand is penalized significantly more than unmet Lo-priority demand.

— All variables must be non-negative:

$$X_{ijmp}, A_{im}, K_{ii'm}, q \geq 0, \quad \forall i, j, i', m, p \qquad (8)$$

5. Objective Function

The objective is to minimize the overall cost of the resupply operation while meeting as much prioritized demand as possible. There is the possibility that supply node capacity or transportation capacity limitations may be insufficient to allow the system to meet full demand, incurring a penalty. The objective function becomes:

$$Z = q + \sum_{i} \sum_{j} \sum_{m} \sum_{p} v_m \left(h_i + g_{ijp} + gdd_{ijp} \right) X_{ijmp} + \sum_{i=I^{SMU}} \sum_{i'=I^{DD}} e_{ii'} \sum_{m} K_{ii'm} \qquad (9)$$

The first term is the penalty imposed for/r(i_) unmet demand. The second term is the cost of intermediate level supply from operational to tactical tiers. The last term is the cost of the strategic to operational supply tiers. This is DLA's cost to supply the SMUs with stock for the SMUs to, in turn, supply the tactical level units.

Finally, the MARPOM can be stated as:

MARPOM: Minimize Z (given by equation (9))

Subject to equations (1)–(8)

6.   MARPOM Implementation

Using the baseline settings, the General Algebraic Modeling System (GAMS) runs MARPOM with 264 constraint equations and 768 total continuous variables. When using CPLEX as its solver engine, GAMS reaches an optimal solution with an execution time of 0.032 seconds on an Intel Core i7–5500U processor running at 2.4 GHz and 8 GB or RAM. The execution speed is indicative of all the runs made in this thesis.

In addition to implementing the MARPOM in GAMS, we have developed a front-end graphical user interface (GUI). This allows the user to easily make changes to parameters and quickly generate the comma separated value data files used by GAMS. The GUI is written using Microsoft Excel's Visual Basic for Applications and implements a user form with built-in macros. Data matrices of distances and costs, calculations to determine penalty magnitudes, warehouse sizes, and holding costs are included in the spreadsheet which supports the GUI. When opened, the user form displays the parameters used in the last scenario. Once the user inputs new parameters, a single button click will push the new values to the spreadsheet, perform the calculations, and quickly create the input data files for GAMS. Screenshots of the GUI follow in Chapter V.

V.   RESULTS AND CONCLUSIONS

A.   BASELINE SCENARIO

The set of conditions chosen to represent a baseline version of MARPOM is meant to mimic the present USMC logistical scenario in terms of troop deployment, existing SMUs and DDs, and historical demand data. A summary of the input items can be seen in Figure 22.

Figure 22.   Input summary for baseline scenario.

By modifying a DD's capacity, the user may allow a range of options from expansion (capacity larger than current) to the removal of the DD (capacity zero). However, the SMUs' capacity is limited based on the UFC's guidelines. If capacity is not limited at the SMUs' intermediate supply tier, MARPOM shows, based on the current input data, that all of the stock would be allocated to the SMUs. This is because despite having larger holding cost estimates, MARPOM highly favors the SMUs due to the

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penalty associated with DLA's longer ACWT. Also, it is assumed there are no Hi-priority requisitions, because demand for Class IX consumable repair parts is mostly predictable allowing stocking policies which provide high availability and prevent equipment from becoming casualties. Although all demand in the baseline case is Lo-priority demand, MARPOM is designed to be used on multiple Classes of Supply, not just Class IX. Other classes will have higher proportions of Hi-priority requisitions.

The optimal GAMS results show that SMU capacities are filled completely while both DDs and SMUs support their local customers with the exception of SMUO, which also supports MRF-D in Australia. This baseline case accepts an unmet demand penalty for low cost, high volume wheel chocks to Australia, where the transportation costs exceed the unmet demand penalty. A sensitivity analysis for wheel chocks shows that as the penalty multiplier for unmet demand reaches a value of 11.4, for an overall penalty of $11.4 \times 9.90 = \$112.86$/wheel chock, the total penalty is no longer less than the costs of satisfying MRF-D's wheel chock demand (Figure 23). So, the demand is satisfied and the unmet demand penalty drops to zero.
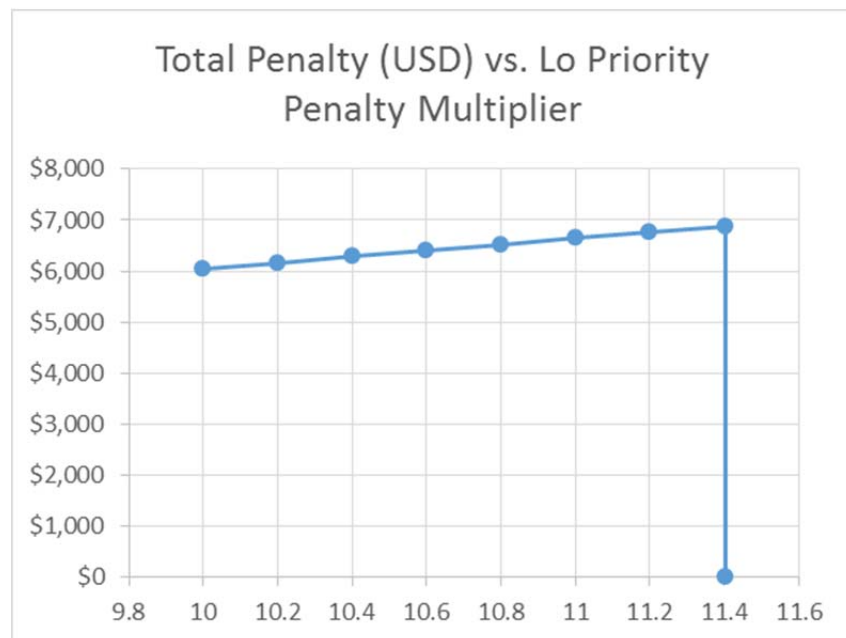

Figure 23.   Sensitivity analysis of unmet demand penalty multiplier in the baseline scenario.

This finding may call into question the stocking policy of low cost, large volume items which have low-priority demand. Purposely deciding not to meet recognized demand for such an item is probably not a policy change which would be realistically considered. However, it begs the question of a centralized vs. decentralized approach to items which have low cost density, or an item's cost divided by its volume. We remind the reader that initial analysis of volume vs. weight for transportation costs showed that volume, not weight, was the driver for cost. Weight is the driving transportation cost only for extremely dense objects such as engine blocks. For example, low cost, large volume items (low cost density), whose transportation and holding costs could exceed the unmet demand penalty, may need to have capacity allocated as far down in the supply chain as possible. Their additional inventory in the system, which a decentralized approach requires, would be minimal as the unit cost is low. High cost density items could be centralized, reducing the total inventory of those items. The extra transportation costs associated with a centralized inventory approach for high cost density items could be quite manageable, because many items would have low volume requirements and hence, transportation and holding costs. Most electronic components or circuit boards meet this criteria. It has been shown that the decrease in inventory required to support a decentralized system at n locations compared to a single centralized location can be estimated as $100(1-\frac{1}{\sqrt{n}})$ (Maister 1976).

For example, consolidating inventories of an item from five locations to a single centralized inventory would result in an overall system inventory reduction of approximately 55% for that item. Much of the savings originates from aggregating the safety stock at the more central location(s). This is a form of risk pooling in that it also reduces the overall system's safety stock requirements by combining the demand from several individual locations into an aggregated regional demand variability (Simchi-Levi et al. 2008).

Since MARPOM can be used for classes of supply which can see frequent Hi-priority requisitions, we investigate the effect of Hi-priority requisitions. The proportion of Hi and Lo priority demand is varied, which impels MARPOM to react as expected. All

Hi-priority demand is filled from stock held at the closest DD given the assumption that there is no time penalty associated with Hi-priority requisitions filled by DLA. The basis for this assumption is that the Priority Material Office will direct an entity in the supply chain, which has the requested Hi-priority item, to provide and expedite its transport to the requisitioner, regardless of the origin. Typically, items which are mentioned in a downed or degraded equipment casualty report (CASREP) as necessary to restore the casualty are transported by air, because CASREP'd items have the highest priority. So, any time penalty associated with DD-supplied vs. SMU-supplied materiel would be minimal for Hi-priority requisitions, because the item will be expedited as soon as possible, regardless of source.

If anything other than immediate fulfillment of Hi-priority Class IX requisitions is possible, then a penalty similar to that imposed on DLA's delay of Lo-priority requisitions can be imposed on Hi-priority demand. Since, Hi-priority requisitions are expedited by any part of the supply system involved in their fulfillment, any delay is an exception and certainly not the result of logistics policy. As such, a delay penalty is not necessary. If delay of CASREP'd items is more common than supposed or more fitting for other materiel classes, then implementing a delay penalty for Hi-priority may influence consideration for new SMUs. The data on which this thesis is based does not include requisition priority. So, the prevalence of Hi or Lo-priority cannot be ascertained. MARPOM, as implemented, allocates Hi-priority capacity to the local DDs, since they have lower holding costs and no more associated delay for Hi-priority requisitions than the SMUs.

With extremely high proportions of Hi-priority demand (above approximately 50%), MARPOM will leave unused capacity at the SMUs in favor of allocating capacity at the co-located DD. Since MARPOM assumes there is no additional fulfillment delay imposed by sourcing Hi-priority requisitions from DDs, capacity allocation becomes primarily an issue of who has the least expensive holding cost when a DD is co-located with the demand node. This tipping point occurs when the volume of Lo-priority demand is less than total available SMU capacity. The interesting side effect of increasing proportions of Hi-priority demand is a decreasing overall system cost, as assessed by our

objective in Equation (9), due to the lower DD holding costs and the co-location of DDs near the largest demands. Even when the air transport cost of Hi-priority supplies to MRF-D is analyzed for increasing proportions of Hi-priority, its impact is not large enough to counter the holding costs savings, which increased allocated capacity at existing DD sites allowed. This is true despite MRF-D's lack of a co-located DD.

B.   PROPOSED REDISTRIBUTION

Since the USMC's portion of the Pacific pivot is a redistribution of existing forces, the total troop numbers remain constant between the current (baseline) and the proposed deployments. Guam receives 5,000 troops and Hawaii accepts an additional 5,000, while MRF-D expands to their full mandate of 2,500 Marines. Okinawa would then draw down respective to the increases elsewhere. The starting point for the redistribution assumes only SMUO and SMUH are active and there are no additional SMUs. The inputs and parameters are summarized in Figure 24.

Figure 24.   Input summary for proposed redistribution scenario.

Working from these initial inputs, a DDPI, DDAU, SMUG, and SMUD are added individually and in combination. Referencing the objective function value in these cases, we find the optimal combination foregoes SMUs in Guam and Australia in favor of local DDs, shown in green in Figure 25. This is due to Guam and Australia representing the two smallest demand nodes in the proposed redistribution scenario. Therefore, the associated penalties with DD supplied materiel is less than the holding cost savings. The first yellow highlighted row in Figure 25 shows that, starting with the extant DDs of DDOJ, DDYJ, DDPH, or DDGM, the status quo has the lowest system cost. This is also the starting point for the redistribution scenario optimal facility selection. The second yellow highlighted row indicates a preference for a SMU in Australia over SMUG. SMUD avoids DD delay penalties and some transportation costs, while the addition of SMUG only avoids DD delays and is expensive holding costs. The green highlighted row takes the result from Guam and shows that another DD in Australia will improve the solution further, almost entirely due to transportation savings. DDPI only improves the objective function if a troop deployment site has no local DD, as the blue rows show.

SMUO	SMUH	SMUG	SMUD	DDOJ	DDYJ	DDPH	DDGM	DDPI	DDAU	Z
X	X			X	X	X	X			158,948
X	X			X	X	X		X		169,217
X	X			X	X	X				173,037
X	X			X	X	X			X	160,400
X	X	X		X	X	X	X			165,690
X	X		X	X	X	X	X			157,972
X	X			X	X	X	X		X	147,517
X	X		X	X	X	X	X		X	149,352
X	X	X	X	X	X	X	X		X	156,094

Figure 25.   Objective function evaluation of progressive SMU and/or DD additions. Z represents the objective function value (cost plus penalties) and X designates the site as activated in MARPOM.

We perform a sensitivity analysis of each DD by making SMUO and SMUH active in combination with a single DD. The results are shown in Figure 26.

SMUO	SMUH	SMUG	SMUD	DDOJ	DDYJ	DDPH	DDGM	DDPI	DDAU	Z
X	X			X						227,490
X	X				X					257,244
X	X					X				244,571
X	X						X			229,138
X	X							X		230,346
X	X								X	257,758

Figure 26.   Objective function contribution of each DD separately.

DDOJ barely edges out some other DDs due to its proximity to the largest demand node. DDGM is second on the list with a slight advantage over the other DDs, DDOJ excepted. This is due to the third largest demand node being on Guam and its central theater location, which minimizes transportation costs to the other demand nodes. However, its centrality to demand is not enough to offset the essentially free transportation from DDOJ to the theater's largest demand node, Okinawa. Although DDPI is not co-located to any demand, it has a generally central location to other demand nodes and its ACF is the least expensive outside the U.S. This accounts for DDPI's strong third place showing in Figure 26. If DLA pursues a centralized inventory approach, DDOJ appears to be the best candidate. Holding costs are only applied to on-hand inventory (1/6 of annual demand, if inventory turns are 6 for DDs), while transportation costs are applied to total annual demand. So, holding cost differences between sites factor much less into the objective function than do transportation costs.

C.   CONCLUSIONS

We have developed MARPOM to help guide optimal distribution of inventories among DDs and SMUs in an area of responsibility, and applied it to the Pacific theater and five select Class IX items. Results show MARPOM produces consistent results based on assumptions made such as distribution of Marines, demand, transportation and holding costs. Some of these could not be fully verified at the time of completing this research, but MARPOM is flexible to accommodate other inputs as they become available. The number of inventory turns per year by SMUs (6 inventory turns) and DDs (4 inventory turns) determine capacity levels. We observe that the reduced storage requirement from inventory turns among SMUs for a given demand is not enough to overcome the DDs'

much lower holding costs. This also plays a factor in the preference of DD capacity over SMU space. While MARPOM shows that the overall system cost is reduced when a local DD is used in the absence of a SMU, this preference runs contrary to the USMC operating principle, which seeks local SMU stock. This would give further credence to the call for greater use of DLA capabilities, possibly in a retail capacity.

The more interesting insight to which MARPOM alludes is the interplay between an item's volume, on which most costs are based, and its cost or, in some instances, the unmet demand penalty. Further investigation of how an item's cost density may affect stocking policy could be useful, but would require more knowledgeable penalty factors. MARPOM further shows that the tyranny of distance still rules the big decisions of cost, with DDGM exhibiting the lowest system cost when DDs are evaluated singly by virtue of their locations relative to the demand nodes.

MARPOM provides "what if" analysis, which can help balance many competing factors at once. Overall, the interplay of the factors shows rational effects on the output, verifying MARPOM's underlying structure. However, its output is only as good as its input. With more inside knowledge of SMU and DD stocks, policies, and operations, MARPOM could be improved further either through better data or model capabilities, as described in the next section.

D. FOLLOW-ON WORK

During the preliminary analysis, volume was found to be the limiting transportation constraint in nearly all reasonable combinations of volume and weight for Class IX parts. It would have to be a very dense item before weight becomes a transportation limitation, on the order of an engine block or pig iron. Oversize items which exceed the standard 463L air shipping pallet dimensions were not considered in this thesis. It was assumed at least one unit of an item could fit on a 463L air shipping pallet. So, a more thorough volume versus weight analysis of all Class IX parts may be in order. If the analysis dictates, weight would need to be calculated as a transportation limitation and added to the Excel front end calculations. This requirement would only exist for Hi-priority items which must travel by air.

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If it is possible to obtain more USMC data which could provide additional insight on SMUs, their usable cubic footage, operating costs, staffing, bay height, operational support guidelines, line item stock, shipping policies, transport frequencies, etc., the model could be improved. Much, but not all, of the same info for DLA sites was unobtainable and therefore reasonable, researched assumptions were made to fill the data fields. SMU personnel could provide an insider's level of knowledge to the model and make the data fields more factual and realistic.

As mentioned previously, using the cost density of an item to apply a centralized or a decentralized inventory policy may have merit. The tyranny of distance in the Pacific leads transportation costs to be sizable, but system inventory savings can be reasonably quantified using a centralized approach (Maister 1976). Focusing efforts on high cost density ($/cubic foot) items would maximize the dollar value of the inventory reduction savings and minimize the transportation costs. This should hold true for items for which volume drives their transportation costs and not item weight, but analysis would need to verify this assumption and find the cost density balance point between centralized and decentralized inventory policies.

Additional analysis techniques which can augment MARPOM's results include a multiple time-step approach which could account for inventory drawdown and restocking policies, such as safety stocks and reorder points. If coupled with stochastic variation to capture the randomness of demand or availability of transport capacity, a much more dynamic variation of MARPOM could be implemented. The advantage of this approach is it will allow inherent supply chain variation and the effects of time to be framed (best case, worst case, etc.), which will provide an even better tool to aid decision making. We anticipate there is ample computing power to handle the added processing required to include these additional features and model extensions.

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