NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA

THESIS

19980102 179

INVENTORY OPTIMIZATION OF CLASS IX SUPPLY BLOCKS FOR DEPLOYING U.S. MARINE CORPS COMBAT SERVICE SUPPORT ELEMENTS

by

Leonard D. Laforteza

June 1997

Principal Advisor:	Kevin R. Gue
Associate Advisor:	Tim L. Phillips

Approved for public release; distribution is unlimited.

DTIC QUALITY INSPECTED 4

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE June 1997	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE INVENTORY OPTIMIZATION OF CLASS IX SUPPLY BLOCKS FOR DEPLOYING U.S. MARINE CORPS COMBAT SERVICE SUPPORT ELEMENTS	5. FUNDING NUMBERS
6. AUTHOR Leonard D. Laforteza	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey CA 93943-5000	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Marine Corps 1st Force Service Support Group, Camp Pendleton, CA 92055-5627	10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

Combat Service Support Elements (CSSEs) for the U.S. Marine Corps deploy with a limited number of spare parts to keep the fighting unit at its highest level of readiness. Items that are requested by the unit, but not carried by the CSSE, are backordered, resulting in lower readiness and additional transportation costs. We show how to determine which items the CSSE should take, and in what quantities, to best support a fighting unit. We have tested our model on data from a recently deployed Marine Expeditionary Unit (MEU), and the results suggest that the MEU could have experienced 13 percent fewer backorders and saved $11,007 in shipping costs by using the model.

14. SUBJECT TERMS Class IX Supply Block, Inventory Management, Backorders	15. NUMBER OF PAGES 87
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

Approved for public release; distribution is unlimited.

INVENTORY OPTIMIZATION OF CLASS IX SUPPLY BLOCKS FOR DEPLOYING U.S. MARINE CORPS COMBAT SERVICE SUPPORT ELEMENTS

Leonard D. Laforteza
Lieutenant, United States Navy
B.S., San Diego State University, 1991

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
June 1997

Author: _____
Leonard D. Laforteza

Approved by: _____
Kevin R. Gue, Principal Advisor

_____
Tim L. Phillips, Associate Advisor

_____
Reuben T. Harris, Chairman, Department of Systems Management

ABSTRACT

Combat Service Support Elements (CSSEs) for the U.S. Marine Corps deploy with a limited number of spare parts to keep the fighting unit at its highest level of readiness. Items that are requested by the unit, but not carried by the CSSE, are backordered, resulting in lower readiness and additional transportation costs. We show how to determine which items the CSSE should take, and in what quantities, to best support a fighting unit. We have tested our model on data from a recently deployed Marine Expeditionary Unit (MEU), and the results suggest that the MEU could have experienced 13 percent fewer backorders and saved $11,007 in shipping costs by using the model.

TABLE OF CONTENTS

I. INTRODUCTION. 1

A. BACKGROUND. 1

B. MARINE AIR GROUND TASK FORCES. 3

1. Marine Air Ground Task Force. 3

2. The Role of a Combat Service Support Element. 4

C. ISSUES LEADING TO THIS STUDY. 6

1. Constraint. 6

2. Problem Statement. 7

a. Embarkation Problem. 8

b. Theater Sustainment Problem. 10

3. Issue to Address. 11

II. REQUIREMENT GENERATION AND SUPPLY SUPPORT. 13

A. CURRENT OPERATION. 13

1. Preparation for a Deployment. 13

2. Operation at Sea. 16

B. DETERMINATION OF NEEDED SUPPLY. 18

C. MEASURING SUCCESS. 19

D. DATA ISSUES. 21

III. MODEL APPLICATION. 23

A. BACKGROUND. 23

B. OBJECTIVE. 24

1. Fill Rate vs. Backorders. 24

2. Availability. 25

C. THE MODEL. 27

1. Introduction 27

2. Algorithm. 27

3. Input to the Model. 28

4. Modeling Demand. 30

5. Weakness of the Model. 30

D. DATA 31

IV. MODEL OUTPUT. 35

A. BACKGROUND. 35

B. RESULTS. 37

C. REDUCED SUPPLY SHIPPING COSTS. 41

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS. 43

A. SUMMARY. 43

B. CONCLUSIONS. 44

C. RECOMMENDATIONS. 44

LIST OF REFERENCES. 47

APPENDIX A - MARINE EXPEDITIONARY UNIT (SPECIAL OPERATIONS CAPABLE) MISSIONS. 49

APPENDIX B - SUBFUNCTIONS OF COMBAT SERVICE SUPPORT. 51

APPENDIX C - CLASSES OF SUPPLY. 53

APPENDIX D - COMBAT ESSENTIALITY CODE. 55

APPENDIX E - GENPAK - SECONDARY REPAIR PARTS. 57

APPENDIX F - GENPAK - CONSUMABLE PARTS. 59

APPENDIX G - EQUIPMENT DENSITY LIST. 61

APPENDIX H - MODEL PROGRAM CODES. 63

INITIAL DISTRIBUTION LIST. 69

LIST OF FIGURES

Figure 1. Problem Description. 7

Figure 2. Combat Service Support Element Distribution System [Ref. 9]. 10

Figure 3. Mission Priority Matrix. 30

Figure 4. Model Recommended Quantities for the 25 Highest Demand Items. 36

Figure 5. Graphs of Mission Priority Factors. 37

Figure 6. Backorder Comparison. 38

LIST OF TABLES

Table 4.1 Model Input Parameters. 36

Table 4.2 Total Backorder Comparison. 39

Table 4.3 Percent Difference In Total Backorders. 39

DEDICATION

In loving memory of

Severo V. Laforteza (1922 - 1997)

I. INTRODUCTION

A. BACKGROUND

> Unless combat forces are supported by a responsive and fail-safe logistics system that can meet their needs under the most adverse circumstances, their operations are doomed to failure. It determines what is possible. Marines must be experts at it, skilled at meeting the inordinate demands for material, supplies, parts, maintenance, transportation - for every category of combat service support. [Ref. 1:p. 36]

The white papers "... *From the Sea*" and "*Forward ... From the Sea*" delineate a new approach to naval operations. Because this approach places an unprecedented emphasis on *littoral* areas, those sea and land areas nearest a coastline, it requires more intimate cooperation between forces afloat and forces ashore [Ref. 2:p. A.1]. This approach also emphasizes the notion of the naval expeditionary force and provides the foundation for Operational Maneuver From the Sea (OMFTS), a concept for the projection of naval power ashore. The OMFTS concept most exclusively affects the United States Marine Corps. As we enter the next century, OMFTS will increasingly guide the Marine Corps in conducting amphibious assaults and in maneuvering directly to objective areas located well inland, with logistics support provided from sea-based assets. The focus of OMFTS is clearly on operational objectives with the sea as the maneuver space.

> Since defenses against missiles are unlikely to be foolproof, ports and air bases (indeed fixed sites of all kinds) will be increasingly vulnerable. So logistical chains will be harder to sustain, which means that expeditionary forces will need to carry more of their supplies with them. Warriors and their machines will find stealth and mobility more useful than armour. [Ref. 3: p. 22]

Increased mobility makes expeditionary forces less vulnerable to the enemy. Tied to this mobility is the concept of the "footprint," the size of the logistics infrastructure. Since a unit with a large footprint is more easily detected by the enemy, it is to the unit's advantage to leave minimal or, ideally, no footprint.

Increasing mobility by reducing the logistics footprint is an important part of OMFTS. There is now a movement away from traditional amphibious assault operations, where heavy build-up ashore was the norm. The move is due to the emerging missions facing our amphibious forces today. Today's most probable conflicts lie in the Third World. The missions that our forces will face require "rapid planning and execution with precisely metered forces and will not involve any form of shore based logistical support" [Ref. 1:p. 40].

The traditional amphibious assault operations placed a burden on commanders, whose mobility was reduced by having to defend large logistics facilities ashore. Since increased mobility necessitates a smaller cache of supplies for deployed armed forces, the decisions made and methods used in stocking and supplying task forces become critical.

We develop a methodology to properly stock a deploying task force with Class IX repair parts. The problem facing a task force in preparation for a deployment is to determine the repair parts, and their quantities, to support the end items given the space constraints on board the ship. To solve the problem, we minimize the expected backorders from the block of supplies taken by the deploying unit. We also propose a scheme to assign *mission priority factors* to items and show how to use that scheme to ensure that the

deploying unit is taking the most important items. Our results suggest that backorders can be reduced by as much as 13 percent using our model.

B. MARINE AIR GROUND TASK FORCES

1. Marine Air Ground Task Force

Marine Air Ground Task Forces (MAGTF, pronounced "Mag-taf") are "integrated combined armed forces structured to accomplish specific missions" [Ref. 4:p. 9], such as amphibious raids, show-of force operations, and clandestine recovery operations. The forces generally fall into one of three categories: Marine Expeditionary Force (MEF), Marine Expeditionary Unit (MEU), or Special Purpose Marine Air Ground Task Force (SPMAGTF). All MAGTFs are, by nature, expeditionary, and comprised of four elements: a Command Element (CE), Ground Combat Element, Aviation Combat Element (ACE), and Combat Service Support Element (CSSE).

The MEF is the primary Marine Corps warfighting force. "It is normally commanded by a Lieutenant General and can range in size from less than one to multiple divisions and aircraft wings, together with one or more force service support groups" [Ref. 4:p. 9]. A MEF is self-sustaining for up to 60 days when deployed.

"The MEU is normally composed of a reinforced infantry battalion, a composite aviation squadron (including attack helicopters, transport helicopters, air refuellers/transport aircraft, light attack fixed wing aircraft, and command and control assets), a MEU service support group, and a command element" [Ref. 4:p. 9]. The MEU is commanded by a Colonel and is equipped to deploy with 15 days of supplies. MAGTF Commanders use forward-deployed

MEUs that are Special Operations Capable (SOC), stationed onboard ships as part of an Amphibious Ready Group (ARG), to provide forward presence and limited power projection overseas. A MEU conducts any of a number of missions, such as amphibious raids, security operations, and show-of-force operations (see Appendix A for a complete list [Ref. 5]).

We study the building of Class IX supply block for a MEU for two reasons: A MEU is the size of force most often requiring that a supply block be built, as it is the principal deploying force; and, we were able to obtain data from the recent deployment of 11th MEU of I MEF from Camp Pendleton, California, with which we could evaluate the results of our model. It is worth noting that although our study focuses only on a MEU, our results could be applied to any size unit.

In missions for which a MEF or a MEU would be unsuitable or too large to implement, a SPMAGTF is task-organized. The SPMAGTFs can be organized, trained, and equipped to conduct a wide variety of expeditionary operations in response to a crisis or a peacetime missions. Their duties can range from noncombatant evacuation to disaster relief and humanitarian missions. [Ref. 4:p. 9]

2. The Role of a Combat Service Support Element

A CSSE is formed around a combat service support headquarters and may vary in size and composition from a support detachment to one or more Force Service Support Groups (FSSG). The CSSE is charged with providing the MAGTF with a full range of Combat Service Support (CSS) functions (see Appendix B [Ref. 6: p. 1.6]). Of all CSS functions, the supply function has the broadest scope. The existence of a supply system adequate to sustain the MAGTF impacts the effectiveness of efforts in the other functional areas, as well

as in the force as a whole. Supply support greatly affects the MAGTF commander's ability to integrate the essential elements of firepower, mobility, and sustainability on which the MAGTF depends [Ref. 6:p. 7.2].

Supplies are divided into nine classes (see Appendix C [Ref. 6:p. 7.2]):

Class I - Subsistence

Class II - Clothing and equipment

Class III - Petroleum, oils, and lubricants

Class IV - Construction materials

Class V - Ammunition

Class VI - Personal demand items

Class VII - Major end items

Class VIII - Medical Supplies

Class IX - Repair parts

We study the stocking of Class IX supplies because they most directly relate to the MAGTF equipment availability. In addition, the majority of supplies that a MEU carries are of Class IX. Class IX supplies include the repair parts needed to support a MAGTF's warfighting equipment. Class IX supplies are repair parts that consist of consumables and secondary repair parts (SecReps). Consumables, or non-repairable items, are discarded after use, such as bolts, screws, etc. SecReps are repair parts such as alternator, and engines that are used to repair an end item like a High Mobility Multipurpose Wheeled Vehicle (HMMWV). Moreover, all SecReps can themselves be repaired.

Maintenance Float, the unit's maintenance department, performs intermediate maintenance on its assigned equipment. Maintenance Float normally performs calibration, repair, or replacement of damaged or unserviceable parts, components, or assemblies [Ref. 6:p. 8.1]. For example, if a HMMWV alternator breaks, it can be taken to Maintenance Float and exchanged for an operational alternator. The mechanics at Maintenance Float will then repair the broken alternator, if possible, and make it available for re-issue.

C. ISSUES LEADING TO THIS STUDY

During planned exercises and wartime operations, a CSSE is responsible for fulfilling requisitions made by the MAGTF. The effectiveness of the CSSE depends, in part, on the items it chooses to carry. Items requested by the MAGTF that the CSSE doesn't carry, or doesn't have on-hand, must be ordered from a remote land-based supply point or a sea-based asset. The CSSE is interested in determining how best to serve the MAGTF by stocking the right items in the right quantities. [Ref. 7]

1. Constraint

The most binding constraint that affects the stocking strategy of a CSSE is the amount of space allowed by the Commanding Officer of the ship to the MEU commander. Prior to a deployment, a ship load-out plan is identified which provides the MEU with space onboard the ship. The MEU then translates the given space into the number of containers.

The decline from four to three ships in an Amphibious Ready Group also has led to a decline in the amount of space given to the CSSE. For example, when CSSE deploys, the items that they take are divided amongst the ships in an ARG. Each ship within an ARG

provides a MEU with a space. As the number of ships decreased, the total amount of space given to the CSSE also decreased.

2. Problem Statement

The decision of what to stock in a land-based CSSE is predicated by what was taken on the deploying ships and aircraft [Ref. 7]. Thus, there are two problems, as illustrated in Figure 1: which items to take on deployment, and which of those items to take to the beach for an operation. We call these *Embarkation* and *Theater Sustainment* problems, respectively.

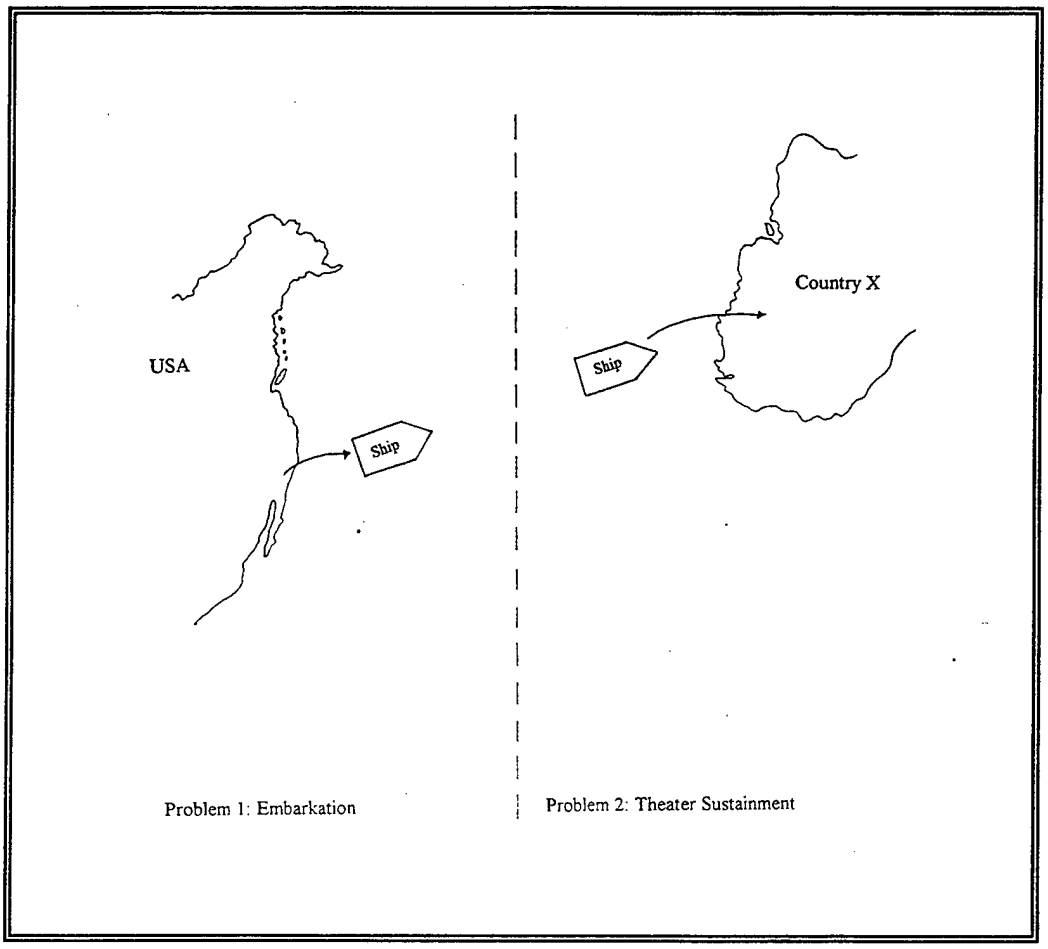

Figure 1. Problem Description

a. Embarkation Problem

Units that are assigned to a MEU are task-organized and require assembling a Battalion Landing Team (BLT), a Composite Squadron, and a MEU Service Support Group (MSSG) from their respective organizations, such as wings, divisions, and Force Service Support Groups, to form a MEU. A Command Element is set up within the MEU to provide command, control, and coordination for planning and executing operations. Once the units are task-organized, they are operationally controlled by the CE.

Approximately six months prior to a deployment, key personnel, such as logisticians, from each of the MEU's units decide which end items (e.g., tanks, HMMWVs, etc.) they should take on deployment to support the mission(s) determined by the MEU Commander. Their recommendations are forwarded to their respective unit commanders. Each unit commander, in turn, makes a recommendation to the MEU Commander. The MEU Commander has the final say on what end items to take; this final list of end items goes into an Equipment Density List (EDL).

The next task is to determine the quantity of repair parts needed to support the end items. The Force Service Support Group (FSSG) collects historical peacetime usage data on parts (both consumables and secondary repair parts) for each of these end-items, and prorates that usage to determine the quantity of each part needed to support the deployment.

Once the deploying ships provide the MEU Commander with the amount of allowed space, FSSG must decide which items, and in what number, to send in the allowable space. Although processes differ slightly among MAGTFs, the MEU Supply Officer reviews all the items for the units and prioritizes these into Combat Essentiality Code (CEC) 5 and 6,

the mission critical items. He differentiates what goes and what stays behind by examining the demand pattern of each repair part. If the item has had low or no demand over the last six months or so, he highlights the item and discusses the item's demand pattern with the requesting unit to see if it still wants the item. The final decision rests with the deploying unit. If there is still room available in the containers, the Supply Officer considers the non-mission critical CEC 1-4 items. This process of prioritizing items continues until the allowed containers are filled.

There are problems with this method. First, the stocking decision does not account for the volume of each item, even though the final stocking decision is volume-constrained [Ref. 7]. For example, the decision to take one additional HMMWV tire instead of three additional HMMWV batteries must consider both the expected demand for these items and the volume they consume in a container.

Second, the current method for stocking may not consider the relative importance of items [Ref. 7]. For example, while the Force Commander needs both HMMWV headlamps and HMMWV batteries, he would probably prefer to run out of headlamps because he considers HMMWV batteries more *important*. Using the current method, however, more HMMWV headlamps might be stocked than HMMWV batteries. (This difficulty is mitigated in some MEFs, where a CEC is a key selection criterion.)

Third, this current process is very time-consuming. The 11th MEU's supply section, which consists of 20 personnel, devotes ten hours per day for six months to develop the stock of supply [Ref. 8]. Assuming a normal five-day work week while ashore, that equates to 24,000 man-hours. While there is no doubt that the supply section worked on

other tasks as well during this period, it is safe to say that developing the supply block for a deploying MEU is extremely time-consuming and labor-intensive. The process of volume trade-off among those items with low demand history takes about a week, for a total of 200 hours [Ref. 8].

b. Theater Sustainment Problem

Once on station in a contingency operation, the deployed ship off-loads its supplies, which are transported ashore to a Combat Service Support Area (CSSA), as shown in Figure 2. The CSSA distributes supplies to the Combat Service Support Detachments (CSSDs). A sea- or land-based resupply asset replenishes the CSSA. Each CSSD carries a cache of supplies for each fighting unit. If an item is out of stock at the CSSA, then it must be sent from the sea- or land-based resupply asset.

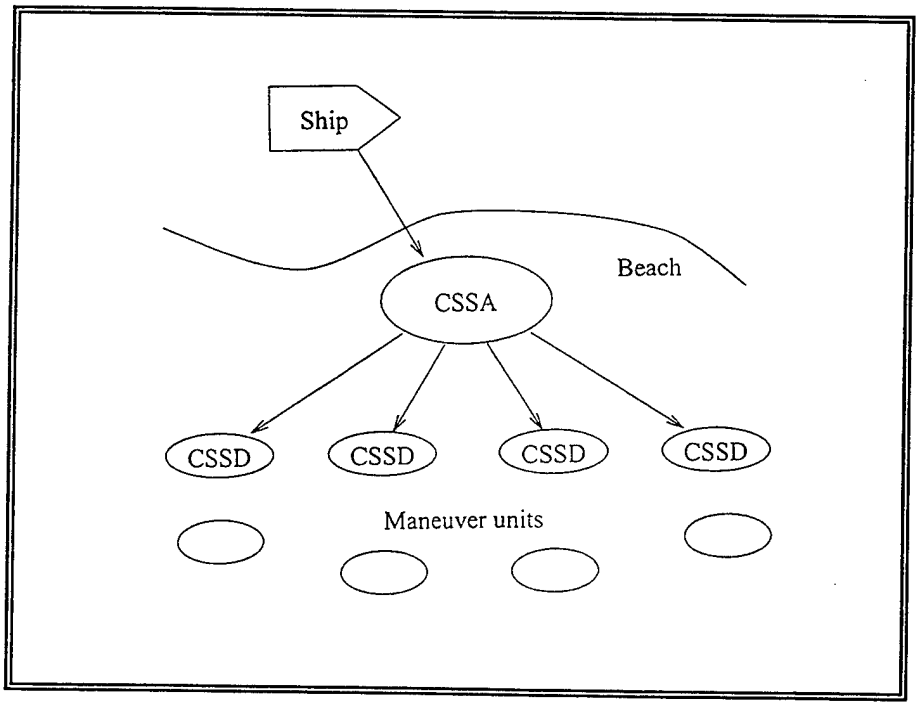

Figure 2. Combat Service Support Element Distribution System [Ref. 9]

Clearly, meeting supply needs from the closest entity in the supply chain lessens the possibility that the fighting unit will be without needed supplies or repair parts. A longer response time from a supply source further along in the supply chain can place the unit at risk. Other factors that may lengthen response time are transportation asset limitations and congested or closed supply routes.

All of the issues discussed in the Embarkation Problem above are also relevant when deciding how to stock a detachment deploying to the beach, except that the volume, although more important in this case, is not the only constraint to consider. As discussed above, the stocking strategy of a CSSE must consider the availability of transportation assets, such as trucks, helicopters, and container handling equipment. Other constraints that must be considered include weather, terrain, sea-state, CSSA availability, enemy threat, distance of resupply, sea-based logistics capability, CSSE mobility, and the unit's stockage levels.

3. Issue to Address

The two problems presented here are closely linked. The Embarkation problem is an input to the Theater Sustainment problem and must be addressed first. We address only the Embarkation Problem -- determining which items the CSSE should take, and in what quantities, to best serve the MAGTF, while not exceeding the capacity constraint.

Not only is the Embarkation problem difficult and time consuming; it must also be solved frequently. At the 1st FSSG in Camp Pendleton, this calculation is done approximately twenty times per year [Ref. 10]. An analytical model to develop supply blocks could yield significant savings in labor cost and effort.

Determining which end items to include in the EDL is a command problem and is addressed by the MEU Commander. When preparing for a deployment, a MEU must consider its 18 possible missions and plan accordingly. Although some missions are stated prior to a deployment, unplanned contingencies can occur. A unit not only has to plan for the missions stated by the Force Commander, but also must anticipate potential crises that may arise during deployment.

II. REQUIREMENT GENERATION AND SUPPLY SUPPORT

A. CURRENT OPERATION

1. Preparation for a Deployment

Prior to a deployment, a MEU Commander solicits inputs from his units on which end items to take in order to perform their assigned missions. After approving the final list of end items, the MEU Commander submits an Equipment Density List (EDL) to the Supported Activities Supply System Management Unit (SMU), the intermediate inventory source of supply which provides supply support for all I MEF units. The EDL lists Principal End Items (PEI), such as tanks, trucks, HMMWVs, and rifles, which are likely to be used by a MAGTF on deployment.

The SMU Operations Section uses the EDL to generate a Deployment Support Generator Package, commonly called "GenPak." Recently, the supply and maintenance battalions determined a way to incorporate the Marine Corps Integrated Maintenance Management System (MIMMS) data, which take into account usage of repair parts, into the GenPak calculation. This is a significant improvement over the former method of determining usage data input to the GenPak, which considered only consumables.

The GenPak provides the deploying unit with a list of consumables and SecReps needed to support the principal end items. The GenPak is reviewed by the deploying unit's CSSE Supply Officer and Maintenance Personnel to determine if both the recommended principal end items and the quantity suggested are essential, or even necessary, to achieve the MEU's prescribed missions. Considerations of availability of transportation, space, and past

experience affect the extent to which the Supply Officer follows the GenPak recommendations. For example, past experience may have shown that a water purification unit is needed in the deployment region if they anticipate a humanitarian relief operation, and the GenPak may fail to list this item. In this case, the Supply Officer would add a request for a water purification unit. In some cases, the GenPak might recommend an artillery recoil mechanism which takes up about 90 ft^3 of space. Due to space constraints and the historically low demand for this item, the recoil mechanism would be deleted from the GenPak recommendation.

After the GenPak has been reviewed and amended ("scrubbed") by the deploying unit, a final copy is submitted to the SMU. The SMU directs General Account and Storage to issue those items that are available in its warehouse; those that are not available are placed on order and ultimately delivered to the deploying unit by the unit's support detachment remaining in the Continental United States (CONUS) or by the Deployment Support Unit (DSU), which is a subordinate section within the SMU which coordinates Class IX support to deployed I MEF units.

Upon receipt of items from the SMU supply warehouse, the CSSE Supply Department builds a supply block in support of principal end items. Supply block consists of consumable and SecRep Class IX supplies. Generally, supply block will consists of Combat Essentiality Code 3 (safety), 5 (combat essential), and 6 (mission essential) repair parts, and of specifically required insurance items to support the EDL for a specific operation as requested by unit commanders [Ref. 11: p. 5].

The CEC is used to identify both combat essential and non-combat essential end items and is broken down into six codes, CEC 1 to 6 (see Appendix D for a complete description [Ref. 12]). Combat essential end items are assigned a CEC code of "1", and critical repair parts are assigned a CEC code of "5" and "6." "The repair part may be a functional part of an end item component or assembly whose failure would make the end item inoperable or incapable of fulfilling its mission" [Ref. 12].

Supply block is placed in a central location within the deploying unit. Upon notification by the ship's Commanding Officer of the allowed space for their containers, the CSSE Supply Officer starts the process of selecting which repair parts go and which stay. This process differs from unit to unit. Some CSSE Supply Officers will use the demand for the repair parts, which is shown on the GenPak, as their primary criterion for ranking the items. Those repair parts with high usage are given loading priority over those with low demand rates. As the container gets filled to capacity, the CSSE Supply Officer starts to look for those repair parts with relatively low or no demand over a certain period (usually six months or so). He then keeps a log of this potential Remain Behind Equipment (RBE). He communicates his intention to leave behind pieces of equipment or parts to his customers, the units (i.e., BLT, ACE, CE, or MSSG) to which the equipment belongs. The CSSE Supply Officer explains to the units the low usage of the equipment as the basis for his recommendation. The potential owner of the equipment will either accept or reject the CSSE Supply Officer's recommendation.

The process continues until all the containers are filled. It is important to note that a MEU carries Class III (Package Oil and Lubricants), minimal Class IV (construction), and

some Class II (clothing and equipment--mostly military clothing that the CSSE Supply Officer intends to sell to the troops). However, the majority of the containers are filled with CEC 5 and 6 Class IX supplies. In some cases, where the containers are not filled, the CSSE Supply Officer will consider CEC 1-4 Class IX supplies for loading.

For other MEUs, the CSSE Supply Officer compares the number of needed containers with the number of allowed containers to determine the percentage of the items that can actually be sent. For example, if the items recommended by the GenPak require 40 containers, and there is room for only 30 containers, he will leave behind 25 percent of each recommended item. RBEs are delivered to the deployed unit the same way as items on order [Ref. 13].

Although it does not happen often, containers that are packed and transported for loading onboard the ship are sometimes left behind because container capacity onboard the ship has been exceeded. This could happen if the allowable number of containers is miscalculated [Ref. 8], or if the ship load out plan changes [Ref. 14].

2. Operation at Sea

Once deployed, the CSSE Supply Department acts as a distribution center, similar to commercial retail, by providing its customers with items it has in stock. If a failed item is a SecRep, it is sent to the Maintenance Float for repair. The repaired item will then be sent to the CSSE Supply Department, where it will be made available for re-issue. The carcass or retrograde of a SecRep that cannot be repaired by the Maintenance Float will stay with the unit until it returns to CONUS.

The SMU is responsible for resupplying the deployed MEU. Requisitions that are not in stock at the CSSE are sent via SALTS, ATLASS, INMARSAT, certified LAN/Server, e-mail, or secure phone to the SMU. The deployed MEU sends backorders for supplies to the SMU at least daily. If the requisitioned item received from the unit is in stock at the SMU supply warehouse, the item is taken to the 1st FSSG Preservation Packaging and Packing (PPP) where it is prepared for shipping. The PPP then forwards the item to the requesting unit by the most expeditious method (UPS, FedEx, or Military Airlift Command) in coordination with the Transportation Management Office (TMO), Camp Pendleton. The item being shipped is tracked by a Transportation Control Number (TCN), which is given to the deployed unit as the primary means of tracking the shipped item.

The TCN, which conceivably contains one or more items, is also used to track shipping cost. It is difficult to determine the cost of shipping an individual item (currently done manually) because the data is not collected in a computer database. Also, when a group of items is shipped under one TCN, cost of shipping is tracked for a TCN and not for the individual NSN listed on the TCN. Determining shipping cost for an individual item in the future should be easier since the TMO is in the process of automating the data collection [Ref. 15].

The TMO ships the item to the unit's next port-of-call. Thus, it is important that the deployed unit communicate changes in its future destination to the TMO. Such communication allows the TMO to re-route and deliver the shipped item to the unit's next destination. This becomes crucial in the delivery of large and bulky parts (e.g., tank engines),

for which guaranteed delivery is difficult even with UPS or FedEx [Ref. 15]. Consequently, bulky items are given priority in container load-out even though their demand is very low [Ref. 14].

Requisitioned items that are not in stock at the SMU supply warehouse are backordered from the item manager or the item manufacturer. The DSU is tasked with tracking these items and shipping them once they arrive at Camp Pendleton.

As arranged with the SMU prior to deployment, deployed units have an option to choose between an automatic or manual Re-order Point (ROP) for a specific item or all items the unit carries. ROP is the quantity to which inventory is allowed to drop before a replacement order is placed [Ref. 16:p. 421]. In almost all cases, ROP is set automatically [Ref. 14]. When set at automatic, ROP is programmed using Supported Activities Supply System (SASSY) and Asset Tracking for Logistics and Supply System (ATLASS) to perform an automatic buy whenever the item falls below the predesignated ROP. Currently, ROP is set at 75 percent of Re-order (RO) quantity, which is the quantity recommended by GenPak after it has been "scrubbed" by the receiving unit [Ref. 17]. Unless specifically requested by the deployed unit otherwise, automatic ROP is canceled about a month before returning to the CONUS since the deployed unit is normally in-transit on their way to the CONUS around this time.

B. DETERMINATION OF NEEDED SUPPLY

All NSNs recommended by the GenPak (see Appendices E and F) to support the principal end items of the deploying unit are based on I MEF peacetime historical usage data. The Marine Corps Integrated Maintenance Management System collects the principal end items

usage history (in peacetime) for the previous 12 months. As mentioned earlier, the EDL (see Appendix G for a sample) specifies the quantity of principal end items a unit is taking. The following illustrates how the SMU uses GenPak to generate the recommended principal end items to support the EDL provided by the deploying unit:

$$ConsumptionRate = \frac{EDLQty}{LUAFQty}$$

where,

EDL Qty = quantity of end items requested by a MEU,

LUAF Qty = Loading Unit Allowance File = total on-hand end item quantity at the I MEF,

Recommended Number of PEI = Consumption Rate * I MEF 12-month historical usage of the PEI.

For example, assume the 11th MEU wishes to take 10 HMMWVs on a deployment. The I MEF has 100 HMMWVs in its inventory. Since the GenPak is based on I MEF historical usage, the GenPak will reveal the total items needed to support all 100 HMMWVs for one year, say in this example, 200 tires. Since the 11th MEU is taking only ten percent of the total inventory, the 11th MEU is entitled to 20 tires.

C. MEASURING SUCCESS

Whenever the MEU returns after a deployment, one of the statistics it provides to the I MEF Force Commander is fill rate, which is the fraction of demands met from initial stock. Normally, the fill rate is multiplied by 100 and is given as a percentage. The deployed units

calculate fill rate to measure supply block performance. Intuitively, the higher the fill rate, the better the supply support the unit receives.

However, the reported fill rate values do not take into account what was loaded on the initial load-out at Camp Pendleton since the fill rate is calculated only while the unit is deployed [Ref. 18]. The fill rate values in this case are not the fraction of demands met from the initial load-out but rather the fraction of demands met from resupply by the SMU at Camp Pendleton. Essentially, the current fill rate values do not give credit to the SMU for building a good supply block for a deploying MEU.

Fill rate is calculated for CEC 5 and 6, CEC 1-4 supplies, and Maintenance Float rate. During its most recent deployment, the 11th MEU fill rates were approximately 56 percent for CEC 5 and 6, 20 percent for CEC 1-4, and 87 percent for Maintenance Float [Ref. 8]. In comparison, the 13th MEU, which deployed for the Western Pacific in 1996, had fill rates of 65 percent for CEC 5 and 6, 70.8 percent for CEC 1-4, and 95.5 percent for Maintenance Float [Ref. 19]. One possible explanation of the differences in fill rate between the 11th MEU and the 13th MEU was the decline in the number of line items that the 11th MEU has taken [Ref. 8]. Prior to 11th MEU's recent deployment, MEUs take on average 6,000 line items. The 11th MEU for their recent deployment took about 3,500 line items [Ref. 18].

Since there is no written performance standard or target goal for fill rates [Ref. 20], a unit's performance is normally assessed by comparing its fill rates to fill rates from past deployments. The desired range for CEC 5 and 6 fill rate is above 50 percent and above 80 percent for Maintenance Float (no desired range was given for CEC 1-4) [Ref. 8].

Another measure of supply support used by the MEU is the Maintenance Readiness Rate. Maintenance Readiness Rate is generated by the MEU and submitted weekly to the Commanding General of 1st FSSG, who in turn submits it to his chain-of command all the way to the Commandant of the Marine Corps [Ref. 21]. The rate measures a unit's equipment (i.e., end items) readiness, and is used to portray each unit's capability to perform its assigned wartime mission [Ref. 22]. The rate simply measures the percentage of end items that are judged "operational." The unit also cites reasons for equipment being non-operational, whether due to supply or maintenance. The average Material Readiness Rate for 11th MEU during its most recent deployment for the 982 reportable end items was 97 percent [Ref. 21].

D. DATA ISSUES

The GenPak does not take into account the volume of individual repair parts nor the volume of allowed containers: The GenPak calculates its recommendation by assuming unlimited container space, which is not the case. In related work using cost-based models, Lau [Ref. 23:p. 31] suggested that as the total allowable volume (budget, in their work) goes down, solutions become more sensitive to the volume of an item and less sensitive to its demand. When the capacity constraint gets tighter, it might appear reasonable to reduce each recommended quantity by the same amount or the same percentage. However, as shown above, this intuitively reasonable approach can be very wrong. [Ref. 23:p. 32]

Another difficulty with the data involves rounding the quantities of prorated repair parts. When a GenPak is generated, it lists recommended NSNs and their quantities to support the

Principal End Items. Since the recommended number is computed for the entire MEF, essentially a MEF average, and computed by dividing the one-year usage by twelve, the output is a fraction rather than an integer. Consequently, rounding must be done to determine the recommended quantity of the item. The current protocol is to round down to the nearest integer fractions less than 0.5 and round up to the nearest integer fractions greater than or equal to 0.5. The rounding protocol does not differentiate between items of different essentiality. For example, items having CEC 5 and 6 are prorated the same way as those in the less essential categories of CEC 1-4.

III. MODEL APPLICATION

A. BACKGROUND

> The objective of Combat Service Support is to sustain and enhance the relative power of the MAGTF at the tactical level of war. This equates to the ability to maintain and sustain organizations and equipment--the firepower and mobility assets--of the MAGTF. [Ref. 6:p. 1.4]

Although our methodology cannot influence the organizational aspect that affects the firepower and mobility of a MAGTF, it can influence the way a MAGTF is outfitted with equipment. The question is: Which items should the Combat Service Support Element take, and in what quantities, to best serve the MAGTF, while not exceeding the capacity constraint?

Currently, when a MAGTF deploys, the load-out decision does not take into account the volume of each item, even though the final load-out decision is volume-constrained. In addition, the method for load-out may not consider the relative importance of items. Moreover, the process is very costly in terms of man-hours. Planning for a deployment with multiple missions further complicates the issue of load-out.

Our methodology takes into account aspects of the problem that the current process does not. In planning for a deployment load-out, we consider the volume of each item, its relative importance, and its historical demand. We also introduce the notion of *mission priority factors* to allow a MAGTF to customize its supply block to be mission-specific.

B. OBJECTIVE

Our objective is to provide the CSSE Supply Officer with a decision aid for making load-out decisions. The MAGTF's objective is to minimize backorders in order to maximize equipment availability and, consequently, readiness. The idea of minimizing backorders is the basis of our model. Before describing the model, we discuss fill rate and expected backorders.

1. Fill Rate vs. Backorders

Fill rate is the percentage of demands that can be met at the time they are placed, while backorders are the number of unfilled demands that exist at a point in time [Ref. 24:p. 24]. In commercial retail, if the customer demand cannot be satisfied, a customer either goes away or returns at a later time when the item has been re-stocked. The first case can be classified as *lost sales* while the second case creates a backorder on the supplier or manufacturer. In military applications, especially in most critical equipment, any demand that is not met is backordered. The backorder is outstanding until a resupply for the item is received, or a failed item is fixed and made available for issue.

These two principal measures of item performance--fill rate and backorders--are related, but very different. Commercial retailers are more interested in the fill rate than in backorders because fill rate measures customer satisfaction at the time each demand is placed. Not only is fill rate easy to calculate, but it also helps retailers form a picture of how well they are meeting customer demand. Experience may tell them that a 90 percent fill rate on an item is not acceptable and will create customer complaints. On the other hand, backorders are not as easy to compute as fill rate. In order to calculate backorders, retailers need to keep track

of the number of customers who still have outstanding requisitions. Furthermore, the backorder numerical value is less intuitive to a retailer than the fill rate.

Unlike commercial retail business, the military is not concerned with *lost sales*. The military measures performance not in terms of *sales*, but in terms of equipment availability.

2. Availability

"Availability measures the degree to which a system is in an operable and committable state at the start of a mission when the mission is called for at an unknown, random point in time; it is often called operational readiness" [Ref. 25:p. 22].

We use the concept of Operational Availability Ao, which can be expressed as:

$$OperationalAvailability = \frac{100 * MTBM}{MTBM + MDT}, \tag{3.1}$$

where MTBM is the mean time between maintenance and MDT is mean down time. If the system is not down for either maintenance or supply, the system is said to be operational. Maintenance and supply availabilities can be expressed as:

$$MaintenanceAvailability = \frac{100 * MTBM}{MTBM + MCMT + MPMT} \tag{3.2}$$

$$SupplyAvailability = \frac{100 * MTBM}{MTBM + MSD} \tag{3.3}$$

where MCMT is mean corrective maintenance time, MPMT is mean preventive maintenance time, and MSD is the mean supply delay time. The MDT in Equation 3.1 is equal to the following:

$$MDT = MCMT + MPMT + MSD. \tag{3.4}$$

The maintenance availability can computed given the maintenance manning, test equipment, and preventive maintenance policy. It can be seen from Equation 3.2 that the maintenance availability depends on the mean time between maintenance, but is independent of the stockage policy, MSD. However, as shown on Equation 3.3, the supply availability is independent of the maintenance policy, and is a function of the stockage policy. [Ref. 24:p. 38]

Sherbrooke [Ref. 24:pp. 19-40] shows that minimizing the sum of expected backorders is equivalent to maximizing Operational Availability Ao, under the following conditions:

1. for a stock level *s*, a reorder or repair of one unit is initiated whenever the level falls to *s*-1,
2. the failure of a single item makes the end item unavailable, and
3. there are no cannibalizations.

The first assumption is approximately met by our system since backorders are relayed to the SMU daily or twice daily from the deploying unit. The second assumption is not realistic for our system (a HMMWV does not become inoperable with a blown headlight, for example),

but is necessary in the absence of reliability block diagrams for all end items. The final assumption is reasonable in peacetime scenarios, but breaks down for contingency operations.

C. THE MODEL

1. Introduction

We develop a model to determine the optimal level of Class IX supplies for a deploying MAGTF. The optimization considers the marginal decrease in expected backorders for an additional increase in repair parts. The calculation of expected backorders takes into account an item's demand, its volume, and the allowed container space.

The model was written using a dialect of the Lisp programming language called Scheme [Ref. 26] (see Appendix H for the code). Runs of the model took 2-3 hours on a Sun Sparcstation 20.

2. Algorithm

The algorithm is

1: For all items i, calculate $\delta_i(s)$
2: While volume consumed < V
3: Let item j be that item with the largest $\delta_i(s)$
4: Add one unit of item j to the block
5: Increment volume consumed by v_j
6: Increment the stock level of item j
7: Update $\delta_i(s)$

where,

$$\delta_i(s) = \frac{EBO_i(s) - EBO_i(s+1)}{v_i},$$

$EBO_i(s)$ = Expected backorders for item i at stock level s,

V = Total volume of the supply block,

v = Volume of an item.

Expected backorders are

$$EBO = Pr\{DI=s+1\} + 2*Pr\{DI=s+2\} + 3*Pr\{DI=s+3\} + \ldots$$

$$= \sum_{x=s+1}^{\infty} (x-s)*Pr\{DI=x\},$$

where the $Pr\{\}$ terms are the steady-state probabilities for the number of units of stock due-in, s is the stock level, and DI is the number of units of stock due-in from repair or re-supply [Ref. 24:p. 25]. Step 3 of the algorithm computes the marginal decrease in expected backorders per volume, for each item. This corresponds to the increase in system effectiveness per volume when an additional unit of that item is chosen for stockage [Ref. 24:p. 30]. The algorithm compares the $\delta_i(s)$ values for all items and adds one unit of the item having the largest $\delta_i(s)$. The process continues until the total volume is filled.

3. Input to the Model

The model requires several inputs from the user:

1. Total available volume. This is obtained from the space given by the Commanding Officer of the ship to the MAGTF Commander. The amount of allowed space is translated into cubic feet.

2. For each item, the demand and cube. The demand is obtained from the GenPak. The volume of each item came from the Defense Logistic Services Center database,

Marine Logistics Base, Albany freight file data, and Cubiscan measurement as measured by the SMU.

3. The planning horizon. The planning horizon is the number of days a unit is expected to be supported. For example, planning guidelines require a MEU to deploy with 15 days of supplies (DOS). Currently, a deploying MEU is outfitted with 30 DOS since the recommended GenPak quantities are based on peacetime historical data [Ref. 10].

4. Mission priority factors. Mission priority factors are intended to customize the supply block according to the MAGTF missions. For example, a MEU has 18 possible missions; we propose that a priority matrix be created of the form shown in Figure 3 to assign a mission priority for each end item for a particular mission as follows: A=critical, B=very important, C=important, and D=desirable.

Next, we assign a factor such as A=1.0, B=0.5, C=0.7, and D=0.4 to differentiate priority of end items having the same Combat Essentiality Code. We do this because a MEU typically has space enough for only CEC 5 and 6 items.

End Item	MEU Missions 1	2	3	4	5	* * *	18
PNSN 1	A	A	A	B	B		A
PNSN 2	A	B	B	B	C		B
PNSN 3	B	A	A	C	D		C
*							
*							
*							
PNSN 532	A	A	B	C	C		D

Figure 3. Mission Priority Matrix

4. Modeling Demand

We were unable to obtain data from which to determine the demand distribution for each item. Because the demand for most items is very low (less than one per month) and failures of repairables are generally unpredictable, we assume that demands for all items occur according to the Poisson distribution. This seems reasonable in light of the fact that only 158 of 19,100 total items have monthly demand greater than one for the entire MEU.

5. Weakness of the Model

The model is greedy in nature, adding at each step a unit of the item that yields the greatest increase in system effectiveness per volume. Consequently, it favors smaller items, all other things being equal. The CSSE Supply Officer occasionally makes decisions that are directly at odds with this tendency of the model, by choosing a bulky item specifically because it is bulky and difficult to ship. These anomalies can be addressed by using minimum quantities as input to the model.

D. DATA

We collected data for our study from several sources. The complete data file is available at the Naval Postgraduate School Systems Management Department.

We obtained repair parts usage data from (the 1st FSSG at Camp Pendleton). Approximately six months prior to their deployment, the 11th MEU submitted an EDL to the SMU containing 532 end items. When the GenPak was calculated, it listed 36,290 repair parts and their corresponding historical usage in support of the 532 end items (PNSNs). Some of the 32,290 repair parts (RNSNs) supported multiple items. For example, the same bolt maybe used to repair a tank and a HMMWV. After consolidating duplicate repair parts and their monthly demand, the number of unique RNSNs dropped to 19,100.

The GenPak does not keep track of the volume of items. The Defense Logistics Center (DLSC) in Battlecreek, MI provided us with 9,167 RNSNs with volume measurements. The Marine Corps Logistics Base in Albany, Georgia provided freight file data containing 17,184 RNSNs with volume measurement. Of these, only 4,613 RNSNs applied to what the 11th MEU took. The SMU purchased a machine called a *Cubiscan* that measures the weight and cubic size of an item. The SMU supply warehouse had about 500 remaining RNSNs on hand for measurement. Out of the 500 RNSNs, 410 applied to the 11th MEU data. This raised our volume measurements to 14,190 out of 19,100 RNSNs.

For the missing volume measurements, we assumed the volume of 0.01 ft^3. This volume represents the median value of the volume of the 14,190 NSNs with known volume. We used the median instead of the mean, 2.3966 ft^3, because the median is more representative of the remaining NSNs. We justified our assumption as follows:

a. From our observation of the data, we observed that the NSNs missing volume data are made up of small items. The first quartile value is 0.072 ft^3. The third quartile value is 0.001 ft^3.

b. Out of the 14,190 NSNs, only 1,010 NSNs have volume greater than 1.0 ft^3.

c. Unlike the mean, the median is not influenced at all by the extreme observations in the data set. There were two NSNs with a combined volume of 5,141.8 ft^3. These two items greatly affected the mean.

d. In general, one could expect that more volume measurements would exist for larger items than smaller items.

The mission priorities for the 532 end items were provided by the G-3 Plans officer at 1st FSSG. He assumed the following in assigning the mission priority:

1. All the end items are necessary for the MAGTF to complete its mission and was already "scrubbed" due to space constraints [Ref. 27].
2. The load-out plan is for the parts and supplies needed to support the end items [Ref. 25].

Mission priorities were assigned with a generic mission in mind. The decision was based solely on his experience and with the help of Marine Corps Bulletin 3000 (MCBul 3000). MCBul 3000 contains reporting instruction procedures and lists the tables of equipment to be reported in the Maintenance Readiness Rate [Ref. 22]. The breakdown of the mission priority for the 532 end items are as follows: 96 items are classified as A; 50 are classified as B; 11 are classified as C; and 35 are classified as D. For the 19,100 NSNs, the mission priority assignment are: 14,927 NSNs are classified as A; 955 NSNs are classified as B; 212

NSNs are classified as C; and 3,006 are classified as D. We assigned the mission priority to an item by choosing the highest priority for all end-items which that item supports.

For the volume constraint, we computed the total volume of the Class IX that the 11th MEU took. MEU-11 took 3,328 RNSNs, which consist of Class II, III, IV, and IX. Out of the 3,328 RNSNs, 2,140 of that are Class IX supplies. Knowing the volume of these 2,140 RNSNs and their corresponding quantities, we calculated the total volume to be 14,754 ft^3. We used this volume in our model so that we could accurately compare the outcome of our model with what the 11th MEU took.

IV. MODEL OUTPUT

A. BACKGROUND

Given the quantities of Class IX supplies and their associated volume taken by 11th MEU, we computed the total volume. We used this same volume as the total volume constraint for our model. We also used data on the demanded items and their associated quantities during the entire deployment. The total number of demanded items during the 11th MEU's deployment was 1,614, and only 1,097 of them were Class IX.

We performed six runs of the model on the data from the 11th MEU, as shown in Table 4.1. Each run corresponded to a different combination of mission priority factors and planning horizon. Our intent was to determine the sensitivity of the model to changes in these parameters. From this analysis, we aim to determine a good initial value for the mission priority factors and planning horizon. Better values will evolve from experience.

We used the 1,097 NSNs as the basis of our comparison. We compared this value with what the 11th MEU carried as part of its initial supply load-out and what our model recommended. The result of this comparison is shown in Figure 4. The demand column represents the total number of items demanded during the entire deployment. The 11th MEU column depicts what the 11th MEU took as part of their initial load-out. The Runs 1 through 6 show what our model recommends. The model recommended quantities are in terms of unit-of-issue. Representative graphs of the changes in mission priority factors are illustrated in Figure 5.

NSN	MON_RATE	DEMAND	11th_MEU	RUN1	RUN2	RUN3	RUN4	RUN5	RUN6
5310004883888	44.35448	22	60	51	82	51	82	82	83
2530012044421	25.1953	740	0	31	49	31	49	49	49
2920011883863	19.98116	18	160	28	43	28	43	43	43
1005000506357	14.03624	3		23	34	23	34	34	34
1005004946602	11.02091	2		20	30	21	30	30	30
5305000826821	10.21128	70	308	19	28	19	28	28	28
1005012044376	10.1784	30	18	20	29	20	29	29	29
1005010838113	9.5683	20		17	25	17	25	25	25
1005009991435	8.52321	106		16	24	16	24	24	24
1005009031296	7.80294	100		17	24	17	24	24	24
1005009372250	5.0365	75	190	14	19	14	19	19	19
5965000433463	4.68209	46	33	13	17	13	17	17	17
1005011130321	4.15154	2	50	13	17	13	18	17	18
5330011343786	4.14658	28	40	13	17	13	17	17	17
5995013100335	4.05896	5	20	13	18	13	18	18	18
5305011582041	3.88847	7	12	11	15	11	15	15	15
6135010363495	3.27804	328	1788	10	14	10	14	14	14
5330007409550	2.99656	4	60	10	13	10	13	13	13
1005011343629	2.86766	49	49	10	13	10	13	13	13
5305011583164	2.68693	73	25	10	13	10	14	13	14
6240000190877	2.67447	2	24	11	15	11	15	15	15
5310011231421	2.67284	12	88	11	15	11	15	15	15
5985013401043	2.65468	67	14	11	15	11	15	15	15
5340013464291	2.44882	63	10	10	13	10	13	13	13
2920011757214	2.18802	1	100	9	12	9	12	12	12

Figure 4. Model Recommended Quantities for the 25 Highest Demand Items

	Mission Priority Factor				
Run	**A**	**B**	**C**	**D**	**Planning Horizon**
1	1.0	0.8	0.6	0.5	15 days
2	1.0	0.8	0.6	0.5	30 days
3	1.0	0.5	0.2	0.1	15 days
4	1.0	0.5	0.2	0.1	30 days
5	1.0	1.0	1.0	1.0	30 days
6	1.0	0.05	0.05	0.05	30 days

Table 4.1 Model Input Parameters

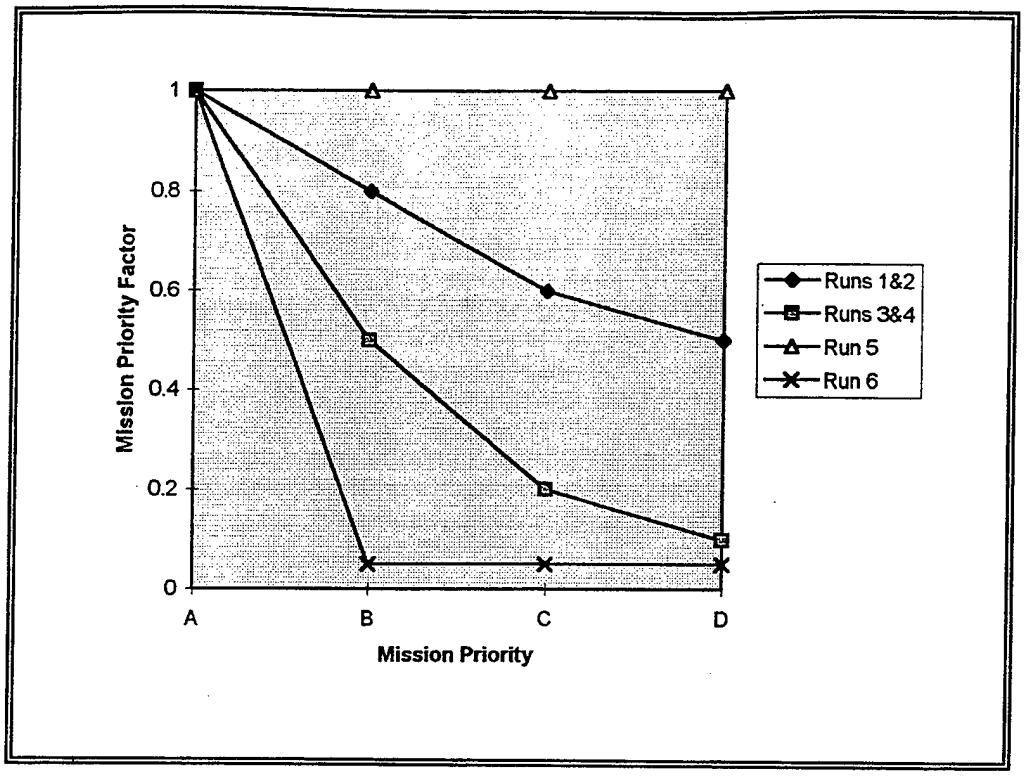

Figure 5. Graphs of Mission Priority Factors

B. RESULTS

The top 25 recommended quantities, sorted according to the item's demand from highest to lowest, is shown in Figure 4. From the results, we calculated the difference between the actual Class IX demand during the 11th MEU's deployment and what the unit took as part of its initial Class IX supply load-out. We performed the same calculation between the actual demand and what the model recommended.

We computed the number of backordered items as follows: Given what was demanded and what was supplied, if the number supplied is greater than or equal to the number demanded, then the number of items backordered is zero; otherwise, the backordered quantity

is the difference between what was supplied and what was demanded. The result of this comparison is shown in Figure 6.

NSN	MON_RATE	11th_MEU-1	RUN1-1	RUN2-1	RUN3-1	RUN4-1	RUN5-1	RUN6-1
5310004883888	44.35448	0	0	0	0	0	0	0
2530012044421	25.1953	740	709	691	709	691	691	691
2920011883863	19.98116	0	0	0	0	0	0	0
1005000506357	14.03624	3	0	0	0	0	0	0
1005004946602	11.02091	2	0	0	0	0	0	0
5305000826821	10.21128	0	51	42	51	42	42	42
1005012044376	10.1784	12	10	1	10	1	1	1
1005010838113	9.5683	20	3	0	3	0	0	0
1005009991435	8.52321	106	90	82	90	82	82	82
1005009031296	7.80294	100	83	76	83	76	76	76
1005009372250	5.0365	0	61	56	61	56	56	56
5965000433463	4.68209	13	33	29	33	29	29	29
1005011130321	4.15154	0	0	0	0	0	0	0
5330011343786	4.14658	0	15	11	15	11	11	11
5995013100335	4.05896	0	0	0	0	0	0	0
5305011582041	3.88847	0	0	0	0	0	0	0
6135010363495	3.27804	0	318	314	318	314	314	314
5330007409550	2.99656	0	0	0	0	0	0	0
1005011343629	2.86766	0	39	36	39	36	36	36
5305011583164	2.68693	48	63	60	63	59	60	59
6240000190877	2.67447	0	0	0	0	0	0	0
5310011231421	2.67284	0	1	0	1	0	0	0
5985013401043	2.65468	53	56	52	56	52	52	52
5340013464291	2.44882	53	53	50	53	50	50	50
2920011757214	2.18802	0	0	0	0	0	0	0

Figure 6. Backorder Comparison

We grouped the number of backordered items according to their mission priority (see Table 4.2). The demand column shows the number of demands during the six-month deployment in each mission priority category. The 11th MEU column shows the sum of the unit's backordered items. The Runs 1 through 8 columns show the total number of backorders the 11th MEU would have had if they had taken what our model recommends. The parameters used for the runs are shown in Table 4.1.

Category	Demand	11th MEU	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
A	6,417	4,134	3,977	3,700	3,963	3,688	3,700	3,674
B	292	224	202	196	203	197	196	210
C	86	85	76	75	76	75	75	77
D	281	261	112	107	128	119	106	125
Total	7,076	4,704	4,367	4,078	4,370	4,079	4,077	4,086

Table 4.2 Total Backorder Comparison

The results suggest that the model would have provided a better mix of supplies than that actually taken by the 11th MEU. The supply block recommended by the model would have led to fewer backorders in every mission priority category, for all combinations of parameters. For example, in Run 1, the model has 3.8 percent fewer backorders than that of the 11th MEU for category A; 9.8 percent fewer for category B; 10.6 percent fewer for category C; and 57.1 percent fewer for category D. For the same mission priority factors, but with 30 days instead of 15 days planning horizon, Run 2 showed a reduction of 10.5 percent in backorders for category A; 12.5 percent for category B; 11.8 percent for category C; and 59.0 for category D. The comparison for the other runs is shown in Table 4.3.

Category	11th MEU	Run 1	% Diff	Run 2	% Diff	Run 6	% Diff
A	4,134	3,977	3.80	3,700	10.50	3,674	11.13
B	224	202	9.82	196	12.50	210	6.25
C	85	76	10.59	75	11.76	77	9.41
D	261	112	57.09	107	59.00	125	52.11

Table 4.3 Percent Difference in Total Backorders

As expected, Run 6 provided us with the best supply for category A by having the least number of backorders because we set a much higher mission priority factor for category A than for the others. As a result, the model made room to stock more category A items, while carrying fewer of the items in categories B through D.

The mission priority factors had little effect on the results of our model. As we varied the mission priority, as in runs 1, 3, 5, and 6, the output did not change considerably. We believe this is because the large majority of NSNs (78 %) were classified category A. However, we saw a change in the output as we went from 15 to 30 days planning horizon. Supply blocks built with a 30-day planning horizon performed significantly better.

The potential to further decrease the number of backorders exists with input from the user. Users consider, among other things, their intended mission or missions and past experiences in determining the kind and quantity of supplies that they should take. This is evident from what the unit took during its last deployment, compared to the GenPak recommendation. For example, the 11th MEU took 1,788 non-rechargeable batteries to support 13 of its radio sets. Apparently the user had a significant input on the quantity taken, considering that the historical monthly demand for the battery is 3. The total demands for non-rechargeable batteries for the entire deployment was 328.

Another apparent input from the user was on the electrical coil. The unit took 100 of these to support 51 of its radio set controllers. That quantity is almost fifty times the historical monthly demand of 2.18802 per controller per month. The actual total demand for this item was one.

The user's input paid off in some cases, as in the battery example above; however, there are instances where apparent unit input led to backorders. For instance, the unit decided not to stock track shoe pads, an item that supports one Assault Amphibious Vehicle. The decision not to stock this part, even though there was a 25.1953 historical monthly usage for it per vehicle, did not help the unit. The unit demanded 740 track shoe pads during its deployment.

To facilitate user interaction, the model allows the user to specify minimum or maximum quantities. For minimum quantities, the user specifies these for each NSN and subtracts the appropriate volume from total available volume. The model runs as before, except the marginal decrease in expected backorders for these items is calculated from the minimum quantities instead of zero.

The user may also assign maximum quantities for items. If a maximum is reached, that item is assigned its maximum quantity and removed from the pool of candidate items as the algorithm continues to build the block. Maximum quantities may be appropriate for very expensive or scarce items.

C. REDUCED SUPPLY SHIPPING COSTS

In addition to reducing readiness, backorders also carry a financial penalty in the form of shipping costs. Because each backorder from a deployed unit is filled from Camp Pendleton, and often uses premium transportation, the shipping costs of backorders have historically been in the hundreds of thousands of dollars [Ref. 15]. For the 11th MEU, shipping costs were $229,887 for all classes of supplies [Ref. 28].

Using the best run of our model, which had a total 13.3 percent fewer backorders, we estimate that the 11th MEU would have saved $11,007 in shipping costs with the recommended supply block. (We assumed that 36 percent of the shipped items are Class IX. This percentage corresponds to the Class IX supplies that the 11th MEU took as part of its initial load-out at Camp Pendleton.)

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

Increasing mobility by reducing logistics footprint is an important part of the Operational Maneuver from the Sea concept. Since increased mobility necessitates a smaller cache of supplies for deployed armed forces, the Marine Air Ground Task Forces in particular, the decisions made and methods used in stocking and supplying task forces become critical. In Chapter I we gave an overview of the task forces organization, presented the research problem, and stated the objective of the thesis. We started our discussion by defining a MAGTF, and then moved to a unit within a MAGTF, the MEU, to point out the role of a Combat Service Support Element in providing supply support to the MAGTF. In particular, we focused our attention on Class IX supplies.

In Chapter II we discussed the current operation of a Marine Expeditionary Unit, both prior to deployment and at sea. We also explained how, with the help of the "GenPak," a deploying unit determines what Class IX supplies to take and how the current supply support is being evaluated. We noted a number of problems with the current method of building a supply block.

In Chapter III we presented our model and introduced the notion that backorders are superior to fill rate as a measure of supply support. We established backorders as the basis of our model. We used this idea as a way to maximize availability and, consequently, enhance readiness. The chapter concluded with the discussion of the data.

In Chapter IV we examined the results of the model. We conducted sensitivity analysis on the model, and compared the results with the 11th MEU's initial stock of supplies. Lastly, the chapter pointed out the costs of supply backorders.

B. CONCLUSIONS

The FSSG responded favorably to the outcome of the model [Ref. 29]. Our results suggested that the model could be used to reduce backorders by more than 10 percent in all mission priority categories with no interaction by the user.

User interaction could further reduce the total number of expected backorders. We contend that the model would not only increase the readiness of deploying MAGTFs, but also significantly reduce the costs of supporting them. We estimated that an FSSG could potentially save tens of thousands of dollars annually by using the model.

There is a significant improvement in the supply block when using a 30-day planning horizon, over the standard 15-day. The results were not very sensitive to mission priority factors.

C. RECOMMENDATIONS

1. We recommend that our model be adopted to build Class IX supply blocks for deploying MAGTFs. For the input to the model, we recommend that the user select 30 days for the planning horizon.

2. As we mentioned earlier, our model can be customized to recommend supplies for a specific mission or multiple missions. We recommend that a matrix similar to Figure 3 be developed. The matrix could be simplified by grouping similar missions into the same

category. In addition, the matrix could be extended to take into account interdependency of items. For example, a gas generator will not function without a spark plug.

3. We recommend that the Marine Corps record demand data for deploying MAGTFs. The data should be collected on specific units, but should be set up to be easily aggregated into groups of MEUs or even a MEF. The data should be keyed to the type of mission fulfilled by the unit so that future supply blocks could be mission-specific.

4. In terms of supply support measurement, we recommend tracking backorders. Although fill rate tends to have clearer meaning to commercial suppliers, the rate does not have the same meaning in military applications. Using the concept of backorders, a unit can determine the status of its supply support not just when the order was placed, but up to the time the item is received.

5. Finally, we recommend that further study be conducted to develop stockage strategies for multi-echelon battlefield distribution problems. The research should consider readiness, the availability of transportation assets, the security of lines of communication, and the need to reduce logistics footprint.

LIST OF REFERENCES

1. Labrecque, T.P., Cdr, USN, *Sea Based Logistics: Viable or Not*, Marine Corps Gazette, Marine Corps Gazette, January 1990.

2. *Operational Maneuver From the Sea: A Concept for the Projection of Naval Power Ashore*, Marine Corps Concept Paper, June 1996.

3. *The Future of Warfare*, The Economist, March 8, 1997.

4. Marine, Official Magazine of the Marine Corps, Almanac 1997, February 1997.

5. *The 18 MEU (SOC) Missions*, MAGTF Presentation Team Pocket Guide, October 1, 1990.

6. Fleet Marine Force Manual (FMFM) 4-1, *Combat Service Support Operations*, July 12, 1993.

7. Gue, K.R., Proposal submitted to 1st FSSG, February 28, 1997.

8. Park, H.K., USMC, 11th MEU Supply Officer, Private communication, May 16, 1997.

9. Kang, K. and Gue, K.R., Sea Based Logistics: Distribution Problems for Future Global Contingencies, forthcoming in Proceedings of the 1997 Winter Simulation Conference, 1997.

10. Calleros, S.J., USMC, SMU OIC, Private communication, March 25, 1997.

11. USMC 1st Supply Battalion, 1st FSSG Supply Procedural Notice MC3-29-95, March 19, 1996.

12. Marine Corps Users Manual, UM-4400-124, *Fleet Marine Force SASSY Using Unit Procedures*, April 1994.

13. Calleros, S.J., USMC, SMU OIC, Private communication, January 22, 1997.

14. Turlip, J.D., USMC, SMU Operation OIC, Private communication, May 19, 1997.

15. Gautrau, J.R., USMC, TMO, Private communication, April 17, 1997.

16. Ballou, R.H., Business Logistics Management, Third Edition, Prentice Hall, 1992.

17. Ashbaker, J.L., USMC, DSU OIC, Private communication, May 19, 1997.

18. Park, H.K., USMC, 11th MEU Supply Officer, Private communication, April 18, 1997.

19. MEU Service Support Group-13 Post Deployment Brief Report, WESTPAC 96-2.

20. Turlip, J.D., USMC, SMU Operation OIC, Private communication, May 21, 1997.

21. Akers, D.L., USMC, 11th MEU S-4A Maintenance Management Officer, Private communication, May 19, 1997.

22. Marine Corps Bulletin 3000, "Table of Marine Corps Automated Readiness Evaluation Systems (MARES) Logistics Reportable Equipment," September 25, 1996.

23. Hon-Shiang Lau, The Newsstand Problem: A Capacitated Multiple-Product Single-Period Inventory Problem, European Journal of Operational Research, June 1995.

24. Sherbrooke, C.C., Optimal Inventory Modeling of Systems, John Wiley & Sons, Inc., 1992.

25. Blanchard, B.S., Logistics Engineering and Management, Fourth Edition, Prentice Hall, Inc., 1992.

26. Dybvig, R.K., The Scheme Programming Language, Prentice Hall, 1987.

27. Wirkus, J.E., Memorandum received by the author from Maj Wirkus, USMC, 1st FSSG, G-3 Plans, April 17, 1997.

28. Gautrau, J.R., Documents received by the author from Maj Gautrau, USMC, TMO, May 7, 1997.

29. Turlip, J.D., USMC, SMU Operation OIC, Private communication, June 5, 1997.

APPENDIX A

MARINE EXPEDITIONARY UNIT (SPECIAL OPERATIONS CAPABLE)

MISSIONS

* Amphibious Raids
* Security Operations
* Limited Objective Attack
* Mobile Training Teams
* Noncombatant Evacuation Operations
* Show-of-Force Operations
* Reinforcement Operations
*Civic Actions
* Tactical Recovery of Aircraft, Equipment, and Personnel
* Fire Support Control
* Counterintelligence Operations
* Initial Terminal Guidance
* Electronic Warfare
* Military Operations in Urban Terrain
* Clandestine Recovery Operations
* Specialized Demolition Operations
* In-extremis Hostage Rescue
* Deception Operations

APPENDIX B

SUBFUNCTIONS OF COMBAT SERVICE SUPPORT

Supply

DETERMINATION OF REQUIREMENTS

PROCUREMENT

STORAGE (TO INCLUDE CARE IN STORAGE)

DISTRIBUTION

SALVAGE

DISPOSAL

Maintenance

INSPECTION AND CLASSIFICATION

SERVICING, ADJUSTMENT, AND TUNING

TESTING AND CALIBRATION

REPAIR AND MODIFICATION

REBUILD AND OVERHAUL

RECOVERY AND EVACUATION

Transportation

EMBARKATION

LANDING SUPPORT

PORT AND TERMINAL OPERATIONS

MOTOR TRANSPORT

AIR DELIVERY

FREIGHT/PASSENGER TRANSPORTATION

MATERIAL HANDLING EQUIPMENT

Services

DISBURSING

POSTAL

EXCHANGE SERVICES

SECURITY INFORMATION

INFORMATION SYSTEMS

LEGAL SERVICES SUPPORT

CIVIL AFFAIRS SUPPORT

GRAVES REGISTRATION

Health Service

HEALTH MAINTENANCE

CASUALTY COLLECTION

CASUALTY TREATMENT

TEMPORARY HOSPITALIZATION AND EVACUATION

General Engineering

ENGINEER RECONNAISSANCE

CONSTRUCTION (HORIZONTAL AND VERTICAL)

FACILITIES MAINTENANCE

DEMOLITION AND OBSTACLE REMOVAL

EXPLOSIVE ORDNANCE DISPOSAL

APPENDIX C

CLASSES OF SUPPLY

Class I - Subsistence including gratuitous health and welfare items. Subclassifications for class I are: A-air (in-flight rations), R- refrigerated subsistence, S-nonrefrigerated subsistence (less combat rations), and C-combat rations (including gratuitous health and welfare items).

Class II - Clothing, individual equipment, tentage, organizational tool sets and tool kits, hand tools, administrative and housekeeping supplies and equipment. Subclassifications for class II are: B-ground support material, E-general supplies, F-clothing and textiles, M-weapons, and T-industrial supplies (including bearings, block and tackle, cable, chain, wire rope, screws, bolts, studs, steel rods, plates, and bars).

Class III - Petroleum, oils, and lubricants; petroleum fuels, lubricants, hydraulic and insulating oils, preservatives, liquid and compressed gases, bulk chemical products, coolants, deicing and antifreeze compounds, together with components and additives of such products; and coal. Subclassifications for class III are: A-air and W-ground (surface).

Class IV - Construction: construction materials to include installed equipment and all fortification/barrier materials. No subclassifications.

Class V - Ammunition: ammunition of all types (including chemical, biological, radiological, and special weapons), bombs, explosives, mines, fuzes, detonators, pyrotechnics, missiles, rockets, propellants, and other associated items. Subclassifications for class V are: A-air and W-ground.

Class VI - Personal demand Items (nonmilitary sales items). No subclassifications.

Class VII - Major end items: a final combination of end products which is ready for its intended use; e.g., launchers, tanks, mobile machine shops, and vehicles. Subclassifications for class VII are: A-air, B-ground support material (includes power generators and construction, barrier, bridging, fire fighting, petroleum, and mapping equipment), D-administrative vehicles (commercial vehicles used in administrative motor pools), G-electronics, K-tactical vehicles, L-missiles, M-weapons, and N-special weapons.

Class VIII - Medical material including medical unique repair parts. Subclassifications are: A-medical/dental material, less blood and blood products, B-blood and blood products.

Class IX - Repair parts and components to include kits, assemblies and subassemblies, reparable and nonreparable, required for maintenance support of all equipment. Subclassifications for class IX are the same as class VII with the addition of T-industrial supplies (includes bearings, block and tackle, cable, chain, wire rope, screws, bolts, studs, steel rods, plates, and bars).

APPENDIX D

COMBAT ESSENTIALITY CODE

CEC	Definition
1	Combat Essential End Item. End items of equipment whose availability in a combat ready condition is essential for execution of the combat and training mission of the command.
2	Non-Critical Repair Part. Repair parts whose failure in the end item will not render it inoperative or reduce its effectiveness below the minimum acceptable level of efficiency, and which do not fit the definition of code 3 or 4 items.
3	Critical Item/Repair Part for Health and Safety of Personnel. Those items that are required for the health and safety of personnel, and which do not fit the definition of code 5 or 6 items.
4	Critical Item/Repair Part for State and Local Laws. Those items that are required to conform with state and local laws, and which do not fit the definition of code 5 or 6 items.
5	Critical Repair Part to a Combat Essential End Item. Repair parts whose failure in a combat essential end item will render it inoperative or reduce its effectiveness below the minimum acceptable level of efficiency.
6	Critical Repair Part to a Non-Combat Essential End Item. Repair parts whose failure in a non-combat essential end item will render it inoperative or reduce its effectiveness below the minimum acceptable level of efficiency.

APPENDIX E

GENPAK - SECONDARY REPAIR PARTS

GENPACK SDR RO INCREASES (SAC-1 ONLY)

(ONLY SDRs WITH EXISTING RIP RO)

EDL ID#	NOMEN	PNSN	EDL QTY	LUAF QTY	LUAF %	PNSN	NOMEN	RVC	CEC	UI	IMEF MONTH MIMMS ID# QTY	PRO MONTH MIMMS ID# QTY	IMEF MONTH MIMMS ALL QTY	SUP
08953A	TANK,COMBAT,	2350010871095	4	80	5.0	2835011787246	REDUCTION GEA	D	5	EA	0.9	0.05	0.9	$38,296.00
ID#/ALL %>>	5.0	CAL RO>>	10	RO INCR>>		1 AA+IMA>>	12	ALLW>>	10	XCS>>	2	NET INCR>>	0	$0
08953A	TANK,COMBAT,	2350010871095	4	80	5.0	2835011978325	GEARBOX,ACCES	D	5	EA	0.6	0.03	0.6	$25,529.00
ID#/ALL %>>	5.0	CAL RO>>	8	RO INCR>>		0 AA+IMA>>	7	ALLW>>	8	XCS>>	0	NET INCR>>	0	$0
08953A	TANK,COMBAT,	2350010871095	4	80	5.0	2835012168639	ENGINE,GAS TU	D	5	EA	2.3	0.11	2.3	494,308.00
ID#/ALL %>>	5.0	CAL RO>>	12	RO INCR>>		1 AA+IMA>>	12	ALLW>>	12	XCS>>	0	NET INCR>>	1	$494,308
08953A	TANK,COMBAT,	2350010871095	4	80	5.0	2910012937131	FUEL CONTROL,	D	5	EA	0.3	0.02	0.3	$12,425.00
ID#/ALL %>>	5.0	CAL RO>>	9	RO INCR>>		0 AA+IMA>>	8	ALLW>>	9	XCS>>	0	NET INCR>>	0	$0
08953A	TANK,COMBAT,	2350010871095	4	80	5.0	2920011687891	STARTER,ENGIN	F	5	EA	0.1	0.00	0.1	$338.00
ID#/ALL %>>	5.0	CAL RO>>	86	RO INCR>>		4 AA+IMA>>	261	ALLW>>	86	XCS>>	175	NET INCR>>	0	$0
08953A	TANK,COMBAT,	2350010871095	4	80	5.0	2920012757477	GENERATOR,ENG	D	5	EA	0.9	0.05	0.9	$6,933.00
ID#/ALL %>>	5.0	CAL RO>>	5	RO INCR>>		0 AA+IMA>>	13	ALLW>>	5	XCS>>	8	NET INCR>>	0	$0
08953A	TANK,COMBAT,	2350010871095	4	80	5.0	2930010673839	COOLER,LUBRIC	D	5	EA	0.2	0.01	0.2	$880.00
ID#/ALL %>>	5.0	CAL RO>>	3	RO INCR>>		0 AA+IMA>>	2	ALLW>>	3	XCS>>	0	NET INCR>>	0	$0
08953A	TANK,COMBAT,	2350010871095	4	80	5.0	2930012106296	IMPELLER,FAN,	D	5	EA	0.1	0.00	0.1	$1,334.00
ID#/ALL %>>	5.0	CAL RO>>	1	RO INCR>>		0 AA+IMA>>	0	ALLW>>	1	XCS>>	0	NET INCR>>	0	$0
08953A	TANK,COMBAT,	2350010871095	4	80	5.0	2990010743488	OIL PUMP ASSE	D	5	EA	0.2	0.01	0.2	$5,613.00
ID#/ALL %>>	5.0	CAL RO>>	1	RO INCR>>		0 AA+IMA>>	6	ALLW>>	1	XCS>>	5	NET INCR>>	0	$0
08953A	TANK,COMBAT,	2350010871095	4	80	5.0	2990012765733	STARTER,ENGIN	F	5	EA	4.3	0.21	4.3	$777.00
ID#/ALL %>>	5.0	CAL RO>>	9	RO INCR>>		0 AA+IMA>>	25	ALLW>>	9	XCS>>	16	NET INCR>>	0	$0
08953A	TANK,COMBAT,	2350010871095	4	80	5.0	4320010730076	PUMP,AXIAL PI	D	5	EA	1.3	0.07	1.3	$5,133.00
ID#/ALL %>>	5.0	CAL RO>>	6	RO INCR>>		0 AA+IMA>>	8	ALLW>>	6	XCS>>	2	NET INCR>>	0	$0
08953A	TANK,COMBAT,	2350010871095	4	80	5.0	4320010759295	MOTOR,HYDRAUL	D	5	EA	0.3	0.01	0.3	$2,679.00
ID#/ALL %>>	5.0	CAL RO>>	2	RO INCR>>		0 AA+IMA>>	1	ALLW>>	2	XCS>>	0	NET INCR>>	0	$0
08953A	TANK,COMBAT,	2350010871095	4	80	5.0	4320012010814	HAND PUMP ASS	F	5	EA	0.3	0.02	0.3	$1,664.00
ID#/ALL %>>	5.0	CAL RO>>	1	RO INCR>>		0 AA+IMA>>	4	ALLW>>	1	XCS>>	3	NET INCR>>	0	$0

APPENDIX F

GENPAK - CONSUMABLE PARTS

ID# GENPACK MONTHLY CONSUMPTION LISTING (PRO QTY >= .5)

EDL ID#	NOMEN	PNSN	EDL QTY	LUAF QTY	LUAF %	PNSN	NOMEN	RVC	CC	UI	IMEF MONTH MIMMS ID QTY	PRO MONTH MIMMS ID QTY	SUP	TOTAL PRICE
00152A	REEL EQUIPM	5805004077722	50	746	6.7	5340-01-142-9478	CRANK, HAND	Z		EA	10.3	0.7	$8.01	$8.01
											00152A ID# SUBTOTAL:			$8.01
00266B	ANTENNA ELE	5985010631574	25	1,039	2.4	5985-00-930-7223	ANTENNA SUBAS	Z	5	EA	30.3	0.7	$0.39	$0.39
											00266B ID# SUBTOTAL:			$0.39
00414A	TOOL KIT,CA	5180005405741	1	49	2.0	6145-00-643-3482	CABLE,POWER,E	F	5	FT	33.4	0.7	$0.29	$0.29
											00414A ID# SUBTOTAL:			$0.29
00482A	DEMOLITION	1375002124589	1	80	1.3	6145-00-548-1296	CABLE,POWER,E	Z	5	FT	41.7	0.5	$0.06	$0.06
											00482A ID# SUBTOTAL:			$0.06
00609A	TOOL KIT,EX	5180007540644	1	15	6.7	1375-00-225-2419	CONNECTOR,DET	Z	5	EA	25.0	1.7	$0.23	$0.46
	TOOL KIT,EX	5180007540644	1	15	6.7	6135-01-351-1131	BATTERY,NONRE	Z	5	EA	8.3	0.6	$2.28	$2.28
											00609A ID# SUBTOTAL:			$2.74
00826A	TELEPHONE S	5805005211320	48	984	4.9	5895-00-543-1881	CASE,TELEPHON	Z	5	EA	18.3	0.9	$12.04	$12.04
											00826A ID# SUBTOTAL:			$12.04
00983A	PANEL MARKE	8345003750227	4	46	8.7	8345-00-227-1700	PIN,PANEL MAR	Z	6	EA	15.2	1.3	$0.05	$0.05
											00983A ID# SUBTOTAL:			$0.05
01360A	TENT	8340002691370	20	641	3.1	8340-00-261-9750	PIN,TENT	Z	5	EA	61.7	1.9	$0.65	$1.30
											01360A ID# SUBTOTAL:			$1.30
01518A	DEMOLITION	1385002124591	9	47	19.1	1375-00-212-4602	CLIP,CORD DET	Z	5	EA	4.1	0.8	$0.09	$0.09
	DEMOLITION	1385002124591	9	47	19.1	1375-00-225-2419	CONNECTOR,DET	Z	5	EA	19.0	3.6	$0.23	$0.92
	DEMOLITION	1385002124591	9	47	19.1	1375-01-033-8317	ADAPTER,PRIMI	Z	5	EA	4.7	0.9	$0.12	$0.12
	DEMOLITION	1385002124591	9	47	19.1	6145-00-284-0394	WIRE,ELECTRIC	Z	5	FT	41.7	8.0	$0.01	$0.08
	DEMOLITION	1385002124591	9	47	19.1	6145-00-548-1296	CABLE,POWER,E	Z	5	FT	16.7	3.2	$0.06	$0.18
											01518A ID# SUBTOTAL:			$1.39

APPENDIX G

EQUIPMENT DENSITY LIST

IT_DE_NU	EDL_QTY	RNSNGMA1	RNSN_NIIN	PNSN	NOMEN	TAMCN
00035A	39	7510002644492	002644492	7510002644492	OFFICE SUPPLY S	C53202
00038G	1	6115001181243	001181243	6115001181243	GENERATOR SET,D	B10217
00141A	26	5895003563902	003563902	5895003563902	CASE,ELECTRONIC	H72282
00149A	4	5950002358730	002358730	5950002358730	COIL,TELEPHONE	H21902
00152A	50	5805004077722	004077722	5805004077722	REEL EQUIPMENT	H23802
00188A	4	6150004989130	004989130	6150004989130	CABLE ASSEMBLY,	H20752
00192B	11	4240002739668	002739668	4240002739668	CLIMBER'S SET,T	J30402
00266A	5	5985004978554	004978554	5985004978554	ANTENNA	H20452
00266B	25	5985010631574	010631574	5985010631574	ANTENNA ELEVATO	A00597
00272A	5	3895002526896	002526896	3895002526896	REELING MACHINE	H23852
00276B	6	5805007156171	007156171	5805007156171	SWITCHBOARD,TEL	A24807
00318B	2	6625005531565	005531565	6625005531565	TEST SET,BATTER	H70222
00349A	4	8345003750226	003750226	8345003750226	PANEL MARKER SE	K46702
00352A	13	5975001875296	001875296	5975002403860	ROD,GROUND	H72132
00357B	12	5965009006401	009006401	5965009006401	HEADSET-CHEST S	H22652
00368A	9	6230004989408	004989408	6230004989408	LANTERN,ELECTRI	K45072
00371A	2	9905005378956	005378956	9905005378956	TAG,MARKER	
00374A	28	5975003141042	003141042	5975003141042	HOOK,RETAINING	H22852
00376B	4	3895003563937	003563937	3895003563937	AXLE AND CRANK	H20552
00380A	14	5180004081859	004081859	5180004081859	TOOL KIT,ELECTR	H79142
00390A	7	5210002672829	002672829	5210002672829	GAGE,CLIMBER'S	H22402
00394A	64	8345005673323	005673323	8345005673323	PANEL MARKER	K46552
00395A	60	8345005907117	005907117	8345005907117	PANEL MARKER	K46602
00396A	42	8345001746865	001746865	8345001746865	PANEL MARKER	K46652
00401B	25	4610002689890	002689890	4610002689890	BAG,WATER STERI	C41102
00403A	16	8340002625767	002625767	8340002625767	REPAIR KIT,TENT	C58702
00411A	9	7310002856155	002856155	7310014127813	STOVE,GASOLINE	K49402
00413A	1	7530002706169	002706169	7530002706169	STATIONERY SET,	C62602
00414A	1	5180005405741	005405741	5180005405741	TOOL KIT,CARPEN	B22202
00420B	1	7520010234498	010234498	7520010234498	FINGERPRINT IDE	K43422
00422C	8	7360001874757	001874757	7360001874757	ACCESSORY OUTFI	C40002
00424B	26	1025009334884	009334884	1025009334884	CHEST,UTILITY	C43402
00432A	1	5180005405740	005405740	5180005405740	TOOL KIT,CANVAS	C65002
00438B	8	4540004696593	004696593	4540004696593	HEATER,IMMERSIO	C49802
00440A	15	4540002666834	002666834	4540002666834	HEATER,IMMERSIO	V45302
00441B	63	5110008131286	008131286	5110008131286	MACHETE,RIGID H	K45202
00447A	9	8340002673129	002673129	8340002673129	FLY,TENT	C48702
00450B	618	7105009350422	009350422	7105009350422	COT,FOLDING	K42362
00453C	16	3590000581837	000581837	3590000581837	BARBER KIT	C41402

APPENDIX H

MODEL PROGRAM CODES

Instructions for running Block Builder

1. Construct an input data file with the following fields separated by spaces: NSN priority-code demand cube,
where priority code is in the set (A,B,C,D). Assume the file is called "infile".

2. Edit the file "setup-block.scm" to suit your preferences. In particular, you might be interested in changing variables such as *env-a*, *env-b*, etc., and *horizon*, which defines the planning horizon.

3. Start Chez Scheme, with a Unix command like "scheme". (Depends on your system.)

4. Assume the total volume to be filled is 100. Type the following in Scheme:

```
(load "setup-block.scm")
(define the-block (make-block 100))
(define items (read-sku-data "infile"))
(build-block the-block items)
```

5. The last command may take some time, depending on how large the data set is. When you get the Scheme prompt back (">"), then type the following to look at ALL the output:

```
(the-block 'report-items)
```

6. You may also ask the-block for the following:

```
(the-block 'volume-occupied)  ; this will be just over the capacity
(the-block 'how-many <NSN>) ; where <NSN> is the NSN of any sku
```

7. To run another problem, return to step 1 and repeat, except you may leave Scheme running (i.e. skip Step 3).

8. To quit Scheme, type:

```
(exit)
```

9. To run a (long) problem in the background (you may log off of a UNIX system), add the following to setup-block.scm:

```
(define the-block (make-block 100))
(define items (read-sku-data "infile"))
(build-block the-block items)
(the-block 'report-items)
```

and type at the UNIX prompt:

```
nohup scheme "setup-block.scm" > outfile.dat &
```

```
;;; setup file for building supply blocks for deploying MEUs

(load "~/scheme/math/math.scm")
(load "~/scheme/math/random.scm")
(load "~/scheme/tools/formatted-read.scm")
(load "~/scheme/tools/io.scm")
(load "~/scheme/tools/list-tools.scm")
(load "~ldlafort/model/memoize.scm")
(load "~ldlafort/model/tables.scm")

;;;==========================================================================
(load "~/scheme/slib/chez.init")
(require 'alist)
(define put-value (alist-associator eqv?))
(define get-value (alist-inquirer eqv?))
(define rem (alist-remover eqv?))
(define increment-value
  (lambda (alist key step)
    (let ((old-value (get-value alist key)))
      (if old-value
          (put-value alist key (+ old-value step))
          (put-value alist key step)))))
;;;==========================================================================

(load "inventory.scm")
(load "block.scm")
(load "read-data.scm")

(define bignum 1000000)

;;; GLOBAL definitions
;;; Define the mission environment variables
(define *env-a* 1.0)
(define *env-b* 0.05)
(define *env-c* 0.05)
(define *env-d* 0.05)
;;; Define the planning horizon (in months)
(define *horizon* 1.0)

; Uncomment these lines to run a nohup job at the Unix prompt:
 (define the-block (make-block 14754))
 (define items (read-sku-data "tinput.txt"))
 (build-block the-block items)
 (the-block 'report-items)
 (wrtln (the-block 'volume-occupied) p)


(define test-items
  (list
   (make-sku 'a 0.7 1 12 1 3)
   (make-sku 'b 0.7 1 2 1 12)
   (make-sku 'c 0.7 1 2 1 1)
   (make-sku 'd 0.8 1 5 1 7)
   (make-sku 'e 0.8 1 11 1 4)
   (make-sku 'f 1 1 1 1 11)
   (make-sku 'g 1 1 1 1 30)))

;;; READ-SKU-DATA
;;; returns a scheme list of sku's, given an input file:
;;; NSN priority demand cube

(define read-sku-data
  (lambda (infile)
    (let loop ((data-matrix (file->matrix "%s %s %f %f" infile))
               (sku-list '()))
      (cond ((null? data-matrix) sku-list)
            (else
             (let ((next-data (car data-matrix)))
               (loop (cdr data-matrix)
                     (cons (make-sku (car next-data)
                                     (cond ((equal? (cadr next-data) "A")
                                            *env-a*)
                                           ((equal? (cadr next-data) "B")
                                            *env-b*)
                                           ((equal? (cadr next-data) "C")
                                            *env-c*)
                                           ((equal? (cadr next-data) "D")
                                            *env-d*)
                                           (else
                                            (error "Bad env variable"
                                                   (cadr next-data))))
                                     1
                                     (caddr next-data)
                                     1
                                     (cadddr next-data))
                           sku-list)))))))))
```

```
;;; Procedures for inventory calculations

;;; for discrete demand distributions

(define expected-fill-rate
  (lambda (stock-level prob-fcn)
    (let loop ((count 0)
               (sum 0))
      (cond ((> count stock-level) sum)
            (else
             (loop (1+ count)
                   (+ sum (prob-fcn count))))))))

;;; EXPECTED-BACKORDERS
;;; finds the expected number of backorders given a current stock level
;;; and probability distn of demand.

(define expected-backorders
  (lambda (stock-level prob-fcn)  ; prob-fcn takes one arg
    (let loop ((count 1)
               (demand (1+ stock-level))
               (ebo 0)
               (last-value bignum)
               (last-last-value bignum))
      (let ((next-value (* count
                           (prob-fcn demand))))
        ; we check the last two iterations to avoid the anomoly that occurs
        ; in prob fcns that are not strictly decreasing
        (cond ((and (and (<= last-value last-last-value)
                         (<= (abs (- last-last-value last-value))
                             0.0000001)) ; the tolerance
                    (and (<= next-value last-value)
                         (<= (abs (- last-value next-value))
                             0.0000001))) ; the tolerance
               ebo)
              (else
               (loop (1+ count)
                     (1+ demand)
                     (+ ebo next-value)
                     next-value
                     last-value)))))))

(define poisson-probability
  (lambda (mean value)
    (* (expt mean value)
       (/ (exp (- mean))
          (factorial value)))))
```

```
;;; Procedures to build a supply block for deploying Marine CSSE's.
;;; Based on algorithms given in Sherbrooke (1993).

;;; MAKE-SKU
;  add weight and upper and lower bounds

(define make-sku
  (lambda (ID                ; identifier
           priority          ; a value between 0 and 1
           cost              ; cost
           demand            ; mean sku/month
           variance          ; demand variance
           cube)             ; physical volume in same units as storage area
    (let ((cost-ratio 0)
          (units 0))
      (letrec ((ebo
                 (memoize
                  (lambda (level)
                    (let ((prob-fcn (lambda (level)
                                      (poisson-probability (* *horizon* demand)
                                                           level))))
                      (expected-backorders level prob-fcn)))))
               (sku
                (lambda (msg . args)
                  (case msg
                    ((demand)          demand)
                    ((priority)        priority)
                    ((cost)            cost)
                    ((variance)        variance)
                    ((cube)            cube)
                    ((ID)              ID)
                    ((ebo)             (ebo (car args)))
                    ((cost-ratio)      cost-ratio)
                    ((set-cost-ratio!) (set! cost-ratio (car args)))
                    ((units)           units)
                    ((add-unit)        (set! units (1+ units)))
                    ((remove-unit)     (set! units (1- units)))
                    ;
                    (else
                     (error 'sku "Unknown message"))))))
        ;
        sku))))


;;; MAKE-BLOCK
;;; defines the supply block
; Takes the following msgs
;
; 'volume  -- the total block volume
; 'volume-occupied -- volume consumed with items
; 'item-list -- list of items in the block, with quantities (an assoc list)
; 'add-item <item> -- add <item> to item-list
; 'how-many <ID> <list-of-items> -- returns the number of units of type <ID>

(define make-block
  (lambda (volume)
    (let ((item-list '()) ; an association list with key 'ID
          (volume-occupied 0))
      (letrec ((report-items (lambda ()
                               (let loop ((items item-list))
```

```
                                (cond ((null? items))
                                      (else
                                       (let ((next-item (car items)))
                                         (wrttab ((car next-item) 'ID) p)
                                         ;(wrttab ((car next-item) 'demand) p)
                                         (wrtln (cdr next-item) p)
                                         (loop (cdr items))))))))
                (block
                 (lambda (msg . args)
                   (case msg
                     ((volume)          volume)
                     ((item-list)       item-list)
                     ((volume-occupied) volume-occupied)
                     ; add an item (object) to the block
                     ((add-item)        (begin
                                          (set! item-list
                                                (increment-value
                                                 item-list
                                                 (car args) 1))
                                          ((car args) 'add-unit)
                                          (set! volume-occupied
                                                (+ volume-occupied
                                                   ((car args) 'cube)))))
                     ((how-many)        (get-value item-list
                                                   (car
                                                    (list-choose
                                                     (cadr args)
                                                     (lambda (i)
                                                       (equal? (i 'ID)
                                                               (car args)))))))
                     ((report-items)    (report-items))
                     (else
                      (error 'block "Unknown message")))))
        ;
        block))))


;;; BUILD-BLOCK
;;; Adds items to the block to fill its unoccupied volume

(define build-block
  (lambda (block candidate-items)
    (let ((capacity (block 'volume)))
      ;
      ; procedure to find the item with highest cost ratio
      (letrec ((find-max
                (lambda (candidate-items)
                  (let loop ((items candidate-items)
                             (best-item '())
                             (best-ratio 0))
                    (cond ((null? items) best-item)
                          (else
                           (let ((next-item (car items)))
                             (if (> (next-item 'cost-ratio) best-ratio)
                                 (loop (cdr items) next-item
                                       (next-item 'cost-ratio))
                                 (loop (cdr items) best-item
                                       best-ratio)))))))))
        ;
        ; compute initial ratios for all items
```

```
(let loop1 ((items candidate-items))
  (cond ((null? items))
        (else
         (let ((next-item (car items)))
           (next-item 'set-cost-ratio!
                      (* (next-item 'priority)
                         (/ (- (next-item 'ebo 0) (next-item 'ebo 1))
                            (next-item 'cube))))
           (loop1 (cdr items))))))
;
(let loop ((items candidate-items))
  ; if the block is full, then stop
  (cond ((> (block 'volume-occupied) capacity))
        (else
         (let ((item-to-add (find-max items)))
           ; add the item with largest cost ratio
           (block 'add-item item-to-add)
           ; recompute ratio for that item
           (item-to-add 'set-cost-ratio!
                        (* (item-to-add 'priority)
                           (/ (- (item-to-add 'ebo
                                              (item-to-add 'units))
                                 (item-to-add 'ebo
                                              (1+ (item-to-add
                                                   'units))))
                              (item-to-add 'cube))))
           (loop items)))))))))


;;; MAKE-EBO-VECTOR
;;; returns a vector of expected backorders for an sku having Poisson demand
;;; with mean <demand>.
;;; requires the procedure <infinite-sum> in math.scm

;;; max units for which to calculate expected backorders
(define *ebo-vector-range* 100)

(define make-ebo-vector
  (lambda (mean)
    (let ((prob-fcn (lambda (value)
                      (poisson-probability mean value))))
      (let loop ((counter 0)
                 (ebo-vec (make-vector *ebo-vector-range* 0)))
        (cond ((= counter *ebo-vector-range*) ebo-vec)
              (else
               (vector-set! ebo-vec
                            counter
                            (expected-backorders counter prob-fcn))
               (loop (1+ counter) ebo-vec)))))))
```

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center. 2
   8725 John J. Kingman Road, Suite 0944
   Ft. Belvoir, VA 22060-6218

2. Dudley Knox Library 2
   Naval Postgraduate School
   411 Dyer Road
   Monterey, CA 93943-5101

3. Director, Training and Education 1
   MCCDC, Code C46
   1019 Elliot Road
   Quantico, VA 22134-5027

4. Director, Marine Corps Research Center 2
   MCCDC, Code C40RC
   2040 Broadway St.
   Quantico, VA 22134-5107

5. Director, Studies and Analysis Division 1
   MCCDC, Code C45
   3300 Russell Rd.
   Quantico, VA 22134-5130

6. Marine Corps Representative. 1
   Naval Postgraduate School
   Code 037, Bldg. 234, HA-220
   699 Dyer Road
   Monterey, CA 93940

7. Marine Corps Tactical Systems Support Activity. 1
   Technical Advisory Branch
   Attn: Maj J.C. Cummiskey
   Box 555171
   Camp Pendleton, CA 92055-5080

8. Defense Logistics Studies Information Exchange 1
   U.S. Army Logistics Management College
   Fort Lee, VA 23801-6043

9. Dr. K.R. Gue, Code SM/GK 1
Naval Postgraduate School
Monterey, CA 93943-5103

10. Officer-In-Charge. 2
SASSY Management Unit
Box 555627
Camp Pendleton, CA 92055-5627

11. Leonard D. Laforteza. 1
16119 Firestone Lane
Chino Hills, CA 91709