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NAVAL POSTGRADUATE SCHOOL

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AN ALTERNATIVE METHOD OF DEVELOPING THE ATLANTIC FLEET ISSUE LOAD LIST

by

Joseph N. Moore

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An Alternative Method of Developing The Atlantic Fleet Issue Load List

by

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ABSTRACT

Upon the outbreak of hostilities, it is anticipated that deployed U. S. ships and those immediately ordered to sea will experience a period when support will only be available from onboard material from Combat Stores Ships and other Mobile Logistics Support Forces. To prepare for this possibility, a projected demand based material requirement is computed annually to support surface ships in a geographical area for a stipulated period. Currently, the Fleet Material Support Office, in determining the load list for Atlantic Fleet Combat Stores Ships, uses a model to calculate the depth of stock, by line item, within a selected range of items, to obtain a projected supply effectiveness goal for this stipulated period. This thesis presents an alternative method (marginal analysis model) of calculating this load list for the Combat Stores Ships and evaluates and compares the two models.

TABLE OF CONTENTS

I. THE INVENTORY PROBLEM ---------------------------- 7

A. THE IMPORTANCE OF INVENTORIES --------------- 7

B. THE SIGNIFICANCE OF FMSO INVENTORY DEVELOPMENT ---------------------------------- 8

C. THESIS PURPOSE/PRESENTATION ----------------- 8

II. INTRODUCTION ------------------------------------ 10

A. GENERAL DESCRIPTION OF THE INVENTORY -------- 10

B. SUBSISTENCE ---------------------------------- 10

C. SHIP'S STORE STOCK --------------------------- 11

D. HIGH USAGE LOAD LIST (HULL) ----------------- 11

E. FLEET ISSUE LOAD LIST (FILL) ---------------- 12

F. CONSTRAINTS ---------------------------------- 12

G. AFS OPERATIONS ------------------------------- 13

III. THE CURRENT ATLANTIC FLEET ISSUE REQUIREMENTS LIST (FIRL)/FLEET ISSUE LOAD LIST (FILL) DEVELOPMENT PROCESS ---------------------------- 15

A. INTRODUCTION --------------------------------- 15

B. INPUT DEVELOPMENT ---------------------------- 16

C. RANGE DETERMINATION -------------------------- 17

D. DEPTH COMPUTATION ---------------------------- 23

1. Forecasting Expected Demand ------------- 23

2. Selecting Appropriate Risk Parameters --- 24

3. Computing Load List Quantities ---------- 26

IV. ANALYSIS OF THE PRESENT FILL DEVELOPMENT PROCESS- 28

A. RANGE AND DEPTH DETERMINATION --------------- 28

B. RISK OF STOCK-OUT ------------------------- 28

V. PROPOSED INVENTORY MODEL --------------------- 31

A. INTRODUCTION ------------------------------- 31

B. APPLICATION OF STATIC MARGINAL ANALYSIS--
A CONSTRAINED MULTIPLE ITEM PROBLEM ------- 34

C. SELECTION OF SAILAWAY KIT ----------------- 44

D. RESULTS OF COMPUTING A REALISTIC MOBILITY
PACKAGE ------------------------------------ 47

VI. EVALUATION AND COMPARISON OF THE MODELS ------- 49

A. TESTING PROCEDURES ------------------------ 49

B. TEST RESULTS ------------------------------ 53

VII. CONCLUSIONS AND RECOMMENDATIONS -------------- 59

APPENDIX A. ACRONYMS ---------------------------- 61

APPENDIX B. EQUIPMENT-RELATED ITEM IDENTIFICATION -- 63

LIST OF REFERENCES ------------------------------ 66

BIBLIOGRAPHY ------------------------------------ 67

INITIAL DISTRIBUTION LIST ----------------------- 68

I. THE INVENTORY PROBLEM

A. THE IMPORTANCE OF INVENTORIES

The development, control and maintenance of inventories of physical goods is a problem common to all enterprises in any area of an economy. Inventories must be and are developed and maintained, both in the public and private sectors of the economy, for several reasons. First, some raw materials used by manufacturers exhibit significant seasonal/cyclical price fluctuations. To take advantage of this price fluctuation phenomenon, manufactures may purchase, when the price is low, relatively large quantities of raw materials to last through the high priced season/cycle. Secondly, sales and profits of manufactures and wholesale/retail merchants can be increased if an inventory of goods is maintained to satisfy customer demands. Thirdly, without inventories, customers would have to wait for orders until shipped/ manufactured. Customers, especially military customers, usually will not or cannot wait for a long period of time for receipt of an order.

Although development, control and maintenance are all important in obtaining the right items and quantities in a given inventory, this thesis addresses an inventory development process within the public sector. Specifically, this thesis looks at the Navys Fleet Material Support Office (FMSO) inventory development process for Combat Stores Ships (AFSs).

B. THE SIGNIFICANCE OF FMSO INVENTORY DEVELOPMENT

The Fleet Issue Load List (FILL) inventory is developed annually by FMSO and is placed onboard AFSs as the primary source of resupply for deployed ships. These deployed ships depend upon the deployed AFS to carry the items and quantities of items needed to carry out deployed peacetime operations. If the item required is not carried by the AFS or an insufficient quantity is obtained from the AFS, an order is usually sent back to a CONUS stock point to fill this item/quantity deficiency. Depending upon the customer ships urgency of need, the item will either be held until the deployed ship returns to CONUS or will be shipped via air or surface transportation. Therefore, if the needs of a customer ship are not satisfied by the deployed AFS, the customer ship is faced with a relatively long waiting (lead-time) period. In the event of war, this lead-time will become critical and the dependency of deployed ships upon AFS supply support will immediately become increasingly acute.

C. THESIS PURPOSE/PRESENTATION

The purpose of this thesis is to determine if another inventory model could provide the items and quantities needed by deployed ships better than the present FMSO model. To make this determination, information was obtained from FMSO and Commander Naval Surface Forces Atlantic (COMNAVSURFLANT) Mobile Logistics/Load Management Office that delineates the AFS mission/current operations and the

current inventory development process. For the sake of brevity, only Atlantic FILL development is discussed in this thesis. Additionally, a search was initiated to find an inventory model that could be applied to the AFS FILL inventory (a constrained multi-item inventory) and that had been previously tested. Such an inventory model was found.

This thesis looks at and explains current AFS operations and the present method used by FMSO to develop an Atlantic FILL. An analysis of this development process is given. Additionally, an alternative method (static marginal analysis) for developing an inventory is presented, and a comparison between the present method and the marginal analysis method is made. Finally, conclusions based on the comparison of the two methods are given, and recommendations to the Naval Supply Command are made.

II. INTRODUCTION

A. GENERAL DESCRIPTION OF THE INVENTORY

The mission of a Combat Stores Ship (AFS) is to resupply U. S. and allied navy ships at sea with certain essential supplies, specifically subsistence items, ship's store stock, High Usage Load List (HULL), and Fleet Issue Load List (FILL) material. Although the AFS determines the number of each item to stock in order to best carry out its mission, higher authority determines which items an AFS carries in its inventory. The methodology of selecting FILL items for stocking on an AFS is the topic of this thesis.

B. SUBSISTENCE

The 250 most commonly used subsistence items which are authorized for messes afloat are carried by the AFS and other Mobile Logistics Support Force (MLSF) units. The range (the composition) of these items is determined by the Food Service Systems Office. Within the MLSF, the items are organized, for management purposes, into categories of freeze, chill, dry and fresh. The Commander Naval Surface Forces Atlantic (COMNAVSURFLANT) develops a standard load, based on accumulated demand, designed to support 21,000 people for 30 days. This standard load is termed a Load I. Additional load lists provide support for 25,000 people (Load II) and 30,000 people (Load III). These load lists

are used for contingency planning purposes and monthly order quantities [1].

C. SHIP'S STORE STOCK

Ship's store stock consists of 138 line items of material to restock basic items required by shipboard personnel. This includes certain clothing items, toiletries, stationary, smoking items, and confections. The range of items is developed by Navy Resale Systems Office (NAVRESO) based on historical demand. The depth (the quantity of each item) carried is based on average monthly demand data. Resupply of the ship's store items is accomplished through NAVRESO delivery contracts which are administered by the appropriate Naval Supply Center [1].

D. HIGH USAGE LOAD LIST (HULL)

The HULL consists of fast moving, bulky items (rags, coffee cups, certain paints, cleaning compound, toilet paper, etc.) which are managed separately (manually reviewed) from FILL items in order to reduce the risk of nonavailability. The 47 HULL items, carried on all MLSF units, are designated by COMNAVSURFLANT. The depth of each item is determined by historical demand data. Additionally, a load list (similar to the subsistence load list) quantity is published and is used for order/loadout purposes [1].

E. FLEET ISSUE LOAD LIST (FILL)

A demand data base is maintained at Fleet Material Support Office (FMSO) in Mechanicsburg, Pennsylvania. Inputs to the data base are made by the deployed AFSs and CONUS stock points. The three stock points on the East coast are Naval Supply Center, Norfolk, Virginia; Naval Supply Center, Charleston, South Carolina; and Naval Air Station, Jacksonville, Florida. The deployed AFSs provide a tape to FMSO indicating the issues of FILL, and extracts are made from the CONUS stock points demand tapes to identify those requisitions submitted by deployed units. The demand base is maintained for 24 months with the oldest month being deleted as a new month of data is added to the file. The development of the FILL is discussed in detail in Chapter III of this thesis.

F. CONSTRAINTS

Inventories held by the AFS are financed through the Navy Stock Fund, Special Accounting Class (SAC) 207. Because the Navy Stock Fund financing, an AFS may place orders for stock so long as the total value of material on hand and on order does not exceed a dollar limit imposed by higher authority. This limit is determined on the basis of perceived need and availability of funds and is referred to as the investment constraint.

Other constraints to be considered are: (1) storage capacity of an AFS, (2) time available in CONUS to load the

supplies, and (3) the number and quality of personnel onboard.

G. AFS OPERATIONS

The three Atlantic Fleet AFSs alternately operating in the Mediterranean Sea are normally resupplied (every 30 or 60 days) by ship from the Naval Supply Center, Norfolk, Virginia. The Pacific Fleet AFSs operating in the Western Pacific Ocean normally reload (resupply) at the U. S. Naval Supply Depot, Subic Bay, Republic of the Philippines (NSD Subic). Because of the greater distance, Atlantic Fleet AFSs face relatively long resupply lead times compared to the near-zero lead times which are normally encountered by Pacific Fleet AFSs reloading at NSD Subic. This difference naturally affects planning and operations. For the sake of brevity, only Atlantic Fleet AFS operations are discussed herein.

The operating schedule of an Atlantic Fleet AFS may best be described in terms of deployment cycles. The deployment cycle for the AFS is normally seven months, with six of those months in service as the on-station AFS and the remainder of the time spent in transit and turnover (material and information transfer from one AFS to another). During the six on-station months, the AFS will conduct (on a monthly basis) a series of operations called underway replenishment, during which material is transferred to other ships. Each month the on-station AFS will receive 9,000 to 15,000 demands

(requisitions) for material. These demands equate to an average of 2,000 measurement tons of provisions and consumables transferred from the on-station AFS (and other MLSF ships operating in the Mediterranean) to customer ships operating in the Sixth Fleet [1].

Upon completion of the six month deployment, the AFS will be relieved and will begin preparations for the return transit to CONUS. During transit, an inventory of FILL material will be conducted and inventory stock records will be adjusted. Upon arrival in CONUS, a new FILL (if a new FILL is to be used during the next deployment) tape is processed (merged) into the ships Master Record File, levels (adjusting the high limits and low limits of carried material) are set, excess material is offloaded, orders (requisitions) are generated to fill material deficiencies and are submitted to the Naval Supply Center, Norfolk. The time spent in CONUS is approximately eight months and the process of preparing (training shipboard personnel, offloading excess material, and ordering, loading, and posting new material to stock records) for the next deployment cycle consumes a large portion of the time in CONUS.

III. THE CURRENT ATLANTIC FLEET ISSUE REQUIREMENTS LIST (FIRL)/FLEET ISSUE LOAD LIST (FILL) DEVELOPMENT PROCESS

A. INTRODUCTION

The Fleet Issue Requirements List (FIRL) is an element of the Navy's Prepositioned War Reserve Requirement (PWRR) which is authorized for support of the surface fleet by OPNAVINST C4080.11B. This FIRL includes all categories of secondary items required to support approved fleet forces except ammunition, bulk petroleum, subsistence, ship's store stock and aviation cognizance material. The Atlantic Fleet FIRL is a defined range and depth of material computed to provide a specified level of resupply support of the total deployed forces for a 90 day endurance period without replenishment. The FIRL computation is essentially based on historical fleet demand. The FIRL is augmented to include items outside the demand-based range under certain limited and specified conditions outlined in OPNAVINST C4080.11B.

The Fleet Issue Load List (FILL) is that portion of the fleet FIRL which is prepositioned in a given AFS. As such, the FILL range and depth are included in the Navy's PWRR. The FILL establishes the range of material which fleet customers may expect to acquire from the AFS, and therefore, becomes a shopping guide catalog. This catalog is published

annually for each fleet by FMSO in conjunction with the annual fleet FILL computation. It is identified as Chapter IV of the Fleet Consolidated Requisitioning Guide-Over-seas (CARGO).

The FILL depth is augmented in the AFS by Peacetime Operating Stocks (POS). OPNAVINST 4441.12A provides the criteria for these augmented loads. The FILL range and depth may also be selectively positioned ashore as part of the overall PWRR. The Atlantic FILL is maintained at the Naval Supply Center, Norfolk. This FILL ashore is identified to the PWRR by project code "PLO".

The development of the FIRL/FILL consists of two major stages: input development and levels computation. The input development stage builds the candidate records. This is done with a series of computer programs that utilize various data files such as the latest two year demand history file. The second stage processes the candidate items through computer programs that forecast demand, build frequency distributions, select appropriate risk parameters, and compute load list quantities.

B. INPUT DEVELOPMENT

The FIRL/FILL is a demand-based load list. As such, the actual demand data reported by various activities is the driving force behind the FIRL/FILL development. A two year Master Demand File is maintained at FMSO. This file consists of MLSF demands reported monthly to FMSO and stock point

demands from surface ships, as extracted monthly from the stock point requisition status file. The MLSF and stock point demands include: (1) industrial (tender and repair ships) ship's demands in support of repairs for other ships, (2) fleet demands for first echelon (MLSF ships) stock replenishments, and (3) ship's own use demands. The stock point data represents: (1) items required by the non-deployed surface ships for day to day operations, and (2) deployed surface ship requirements that were passed to the stock point. In building the FIRL/FILL candidate file (at present this file consists of approximately 180,000 line items), only fleet issue demands are considered. Demand is extracted in terms of deployed demand and expanded demand.

In the Atlantic Fleet, the deployed demand data base consists of all issues by the three Atlantic Fleet AFSs and all stock point demands from deployed surface ships. Fleet issue demands reported for AOs (Fleet Oilers) deckload and HULL items are also included. The expanded demand data base consists of deployed demands plus all stock point fleet issue demands from non-deployed (2nd Fleet) ships. The stock point demands are collected from Naval Supply Center (NSC) Norfolk; NSC Charleston; and Naval Air Station (NAS) Jacksonville [2].

C. RANGE DETERMINATION

As stated in OPNAVINST C4080.11B, the FIRL/FILL consists of three categories of items--Appropriation Purchases

Account (APA), Navy Stock Account--Equipment-Related(NSA-ER), Navy Stock Account--Non-Equipment-Related(NSA-NER). The NSA ER/NER coding is based on the item's Federal Supply Group (FSG). Appendix B lists the FSGs used to code items as Equipment-Related. All APA items are considered Equipment-Related. The segregation of material into these three categories is important in the FILL development process and is discussed below.

The FIRL/FILL is a demand-based load list. Unless an override (an exception) is applied, an item can make the FIRL/FILL only if it passes a series of range criteria which are based on frequency of demand over the most recent two years. FIRL items are those items that pass a specified FIRL range criterion. More specifically, a FIRL item must have an expanded demand frequency of at least eight in a two year period (at present the number of FIRL items number approximately 60,000). An item that fails to pass the FIRL range criterion is called a non-load list item. These items are excluded from the FIRL.

Those items in the FIRL range that also pass a more restrictive FILL range criteria are called FILL items. The FILL range criteria are a combination of two requirements. A FILL item must have had an expanded demand frequency at least as great as a specified value-RC 1- and a deployed demand frequency at least as great as a second specified value-RC 2. An ER item that passes the FIRL range criterion, but not FILL range criteria, is called a "FIRL ONLY" item.

An NER item that passes the FIRL range criterion, but not the FILL range criteria, is considered a non-load list item since OPNAVINST C4080.11B excludes NER items from the "FIRL ONLY" range. These NER items are therefore excluded from the total FIRL [2].

As noted earlier, the item range determined by the above criteria may be modified by exclusion overrides and minimum or mandatory quantity overrides. Furthermore, items may be excluded from the FILL but considered for the FIRL through assignment of a "FIRL ONLY" code [2]. The logic described above is diagrammed in Figure 1.

The FILL range criteria are determined from frequency distributions which are based on the most recent two year demand history of candidate items. Items with exclusion, mandatory, or minimum override assignments are not included in these distributions. The remaining items are included only if they pass the FIRL range criteria.

The Type Commander (TYCOM)--for the Atlantic Fleet FILL-COMNAVSURFLANT--selects the total number of ER and NER items to be included on the FILL. FMSO develops separate frequency distributions for ER and NER items. The distributions are based on demand frequencies over the most recent two year period. FMSO selects from these distributions the ER/NER FILL range cut values that result in the recommended FILL range. The TYCOM recommends the desired FILL composition to Chief of Naval Operations (OP-04) for approval. The ER range cut is used on both NSA and APA items.

FLEET ISSUE REQUIREMENTS LIST (FIRL)/
FLEET ISSUE LOAD LIST (FILL) FLOW CHART

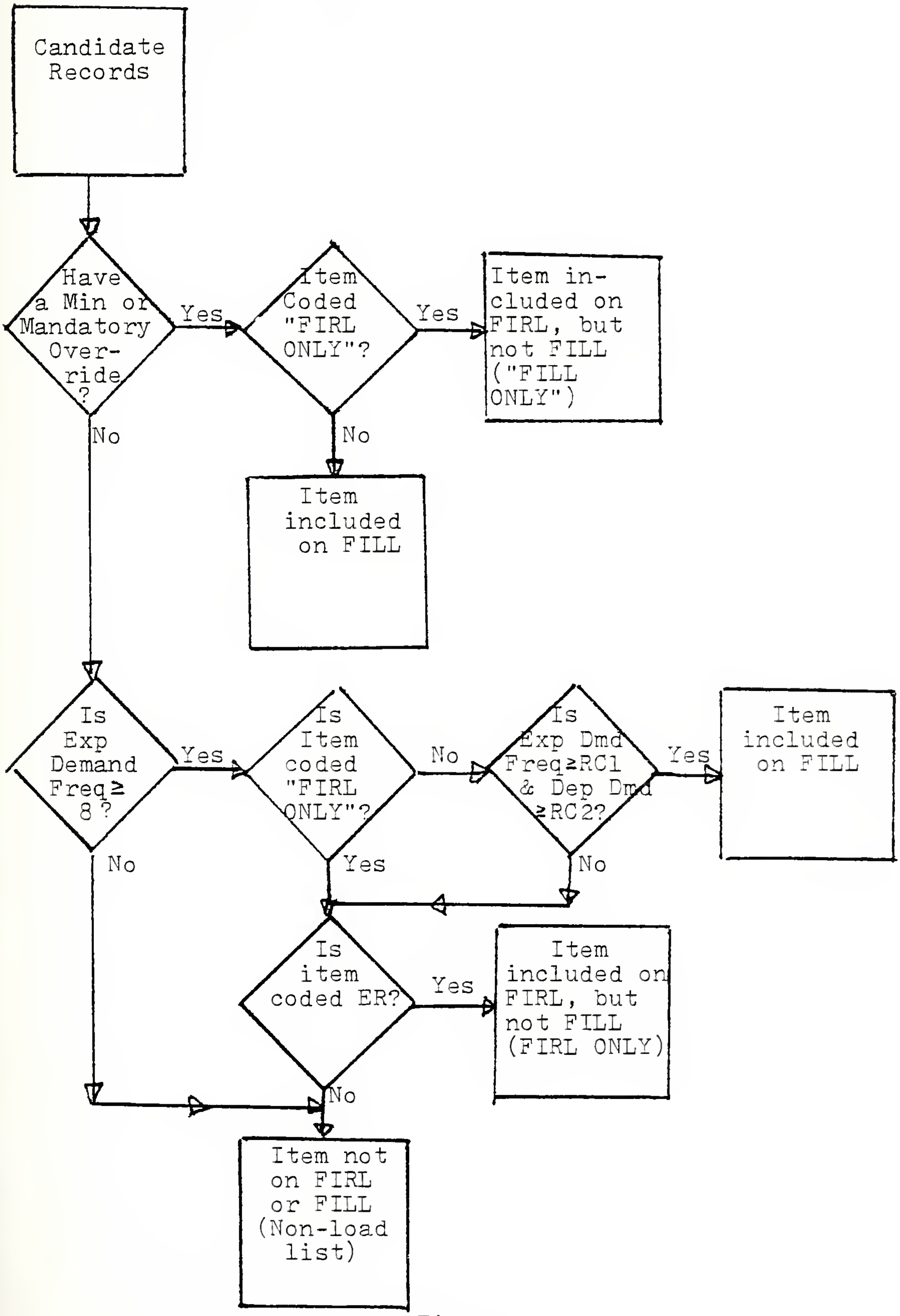

Figure 1

TABLE I

SAMPLE ER FREQUENCY DISTRIBUTION

Total Deployed Demand Frequency (RC 2)	Total Expanded Demand Frequency (RC 1)						
	8	9	10	11	12	13	14
0	25,000	22,040	20,500	18,000	15,100	14,000	13,000
1	24,000	20,000	18,000	16,000	14,900	13,800	12,470
2	21,000	18,000	16,300	15,000	14,450	13,700	11,240
3	18,000	16,000	14,600	14,300	14,100	13,200	10.900
4	17,000	15,000	14,200	14,000	13,900	12,800	10,500
5	16,000	14,800	14,000	13,700	13,400	12,500	10,000
6	15,300	14,000	13,400	13,250	13,000	11,750	9,800
7	15,000	13,900	13,200	13,000	12,800	11,600	9,450
8	14,000	13,500	13,000	12,840	12,020	10,870	9,170
9	12,600	12,500	12,400	11,900	10,950	9,870	8,910
10	9,700	9,650	9,600	9,500	9,250	9,000	8,870

Table I displays a sample frequency distribution similar to the one used by FMSO in the FIRL/FILL development process. This is a two-dimensional distribution with the columns representing the total expanded demand frequency, the rows representing the total deployed demand frequency, and the entries representing cumulative number of items. For example, refer to the column marked "9" and the row marked "3". The entry in that box is 16,000. This means that 16,000 candidate items had at least nine expanded demand frequencies and at least three deployed demand frequencies during the past two years. As an example of the use of the matrix, assume the TYCOM specifies that a range of 12,000 ER items is required for a particular FILL. FMSO will analyze the ER frequency distribution to determine which range cut values will result in approximately 12,000 ER FILL range. Table I shows that an expanded demand range cut value of 12(RC 1) and a deployed demand range cut value of eight(RC 2) corresponds to a 12,020 ER FILL range. In addition, an RC 1 of 11 and an RC 2 on nine result in an 11,900 ER FILL range, and an RC 1 of 13 and an RC 2 of six result in an 11,750 ER FILL range. FMSO provides these various alternative range cuts to the TYCOM. The TYCOM will review these range cuts, make a decision and will recommend the range and range cut values to Chief of Naval Operations (OP-04) for approval [2].

D. DEPTH COMPUTATION

The FIRL/FILL depth computation process consists of computer programs that: (1) forecast expected demand, (2) select appropriate risk parameters, and (3) compute load list quantities. Each of these programs is discussed below.

1. Forecasting Expected Demand

This forecast of expected demand is based on the latest two year demand history for each candidate item. The program computes a demand forecast called Quarterly Average Demand (QAD) and a standard deviation of quarterly demand (σ) for each candidate item.

The QAD is a simple average (mean) of experienced demand.

$$QAD = \frac{\text{Total Demand Quantity over the past 8 Quarters}}{8}$$

The standard deviation is computed as the square root of the variance of demand as follows:

$$\sigma = \sqrt{\frac{\text{Sum of } (Di - QAD)^2 \text{ over the past 8 Quarters}}{7}}$$

where Di = demand quantity by quarter
QAD = quarterly average demand

The quarterly average demand and standard deviation of quarterly demand are computed for both expanded demand and deployed demand. The quarterly average demand provides an estimate of the expected demand for a 90 day period,

while the standard deviation provides a measure of how much the demand fluctuates from quarter to quarter [2].

2. Selecting Approprooriate Risk Parameters

This program is a parameter selection model which is used to determine the risk parameter value necessary to attain the effectiveness goals stated in OPNAVINST C4080.11B. This instruction states that variable level techniques will be utilized to compute stock depth to satisfy 85% of units demanded by the fleet. The minimum item protection associated with the variable techniques will be specified annually by Chief of Naval Operations (OP-04) based upon cost analysis alternatives provided by Commander Navy Supply Systems Command (COMNAVSUPSYSCOM).

The risk of stock-out controls the depth of an item and thus the predicted effectiveness for the load. The acceptable risk of stock-out is defined as:

$$\text{Risk} = \frac{(\lambda)\ (C)\ (A)}{QAD}$$

where

λ (Lambda) = control parameter
C = item unit price
A = item average requisition size (total two year demand quantity divided by the total number of requisitions over the same period)
QAD = item quarterly average demand

The risk is constrained to a maximum of 0.97725 (approximately 98%) and a minimum of 0.02275 (approximately 2%) [2].

The Lambda value (λ) is the control (variable) parameter in the risk equation. Unit Price, Average

Requisition Size, and Quarterly Average Demand are constants for each item for a particular time period. Therefore, varying the Lambda value is the only way to control the risk of stock-out which in turn controls requisition effectiveness.

Conceptually, the risk equation works this way: risk is the complement of protection--i.e. 90% protection is the same as 10% risk. If higher protection is the goal, then risk should be decreased by lowering the Lambda value. Conversely, if lower investment level is desired, the Lambda value should be raised. The purpose of the parameter selection model is essentially to determine the Lambda values which result in predicted effectiveness to meet the goal (85% units effectiveness) stated in OPNAVINST C4080.11B. Several values of Lambda may be tested to attain an acceptable value.

The model described above is called a variable protection model. The risk, and thus protection, may be different across the candidate items because of differences in item characteristics. More specifically, high cost/low demand items will have relatively lower protection than low cost/high demand items. This program also has the option of computing risks based on a units effectiveness goal goal rather than requisitions. Previous loads have used the units effectiveness option. There is also an option in the program known as the fixed protection model. In this model, every item will have the same risk, and thus the same

protection, regardless of unit price or demand frequency. The variable protection option is currently being used because it satisfies the OPNAV guidance at a lower total cost by emphasizing availability of low cost items [2].

3. Computing Load List Quantities

FIRL depth computations are based on the Normal distribution which utilizes an item's computed risk, predicted wartime quarterly average demand (QADm), and predicted wartime standard deviation of quarterly demand (σm). An item's quarterly average demand and standard deviation of quarterly demand are based on actual demand and are augmented by the fleet support factor to obtain estimated wartime requirements. This factor, currently set by OPNAV at 1.5, represents the estimated increase in demand under mobilization conditions. In symbols, an item's QAD or are modified as follows: QADm = (QAD) (1.5)

$$\sigma m = (\sigma)\ (\sqrt{1.5})$$

The risk used in the Normal distribution is based on the Lambda value determined from the parameter selection model. NSA-ER, NSA-NER and APA items may have separate Lambda values. The quantity computed from the Normal distribution is called the FIRL quantity. If the item is a FILL item, FIRL quantity is divided by the number of FILL activities--four (USS SAN DIEGO, USS CONCORD, USS SYLVANIA and NSC Norfolk) in the Atlantic fleet. The new quantity is called the FILL quantity. Any item that passes the FILL range cut will have a minimum FILL quantity of one. After

the FIRL or FILL depth is determined, an item's new load list quantity is compared with its old load list quantity. If the difference between the two quantities is relatively small, the old load list quantity is used rather than the new one. This is done to minimize the workload resulting from numerous depth changes. The load list quantity is then constrained to be at least a dollar's worth of stock. The load list quantity can also be changed through the use of a mandatory override, maximum override, or minimum override [2].

The following is an example of a FIRL and FILL quantity computation:

Unit Price = $1.00
QAD = 100
  = 50
Average Requisition Size = 20

Fleet Support Factor = 1.5
Number of FILLs = 4
Lambda Value (λ) = .1

Compute Risk/Protection

$$\text{Risk} = \frac{(\lambda)(\text{Unit Price})(\text{Average Requisition Size})}{\text{QAD}} = \frac{(.1)(1)(20)}{100}$$

$$= .02$$

Since the computed Risk is less than 0.02275, set Risk to 0.02275.
Protection = 1 - Risk = 0.97725 (Maximum Protection)

Adjust QAD and to obtain Estimated Wartime Requirements

Mobilization QAD = QADm = (QAD) (Fleet Support Factor) = (100) (1.5) = 150

Mobilization Standard Deviation = σm = (σ) (Fleet Support Factor)

$$\sigma m = (50)\ \sqrt{1.5} = 61$$

Compute Load List Quantity (LLQ)

LLQ = QADm + ("t" value) (σ m)   "t" value = 2 when Protection = 0.97725

LLQ = 150 + (2) (61) = 272 = total FIRL Quantity

$$\text{FILL Quantity} = \frac{\text{LLQ}}{\text{No. of FILLs}} = \frac{272}{4} = 68$$

= Represents a minimum quantity to be prepositioned onboard a given AFS and at NSC Norfolk as prepositioned war reserve stock.

IV. ANALYSIS OF THE PRESENT FILL DEVELOPMENT PROCESS

A. RANGE AND DEPTH DETERMINATION

The development of the FIRL/FILL consists of two stages: input development and levels computation. Input development consists of gathering demands from deployed and non-deployed fleet units and building a file of candidate items. The present levels computation stage consists of two separate steps. First, the TYCOM selects, based on his judgement, the number (range) of ER and NER items to be included on the FILL. Secondly, after the range has been selected and approved, FMSO computes the depth of these items to be included on the FILL.

With any given constraint (size, weight, dollar value, etc.), the range and depth of items to be included in the FILL on any inventory package depend on each other. Therefore, FILL range and depth should be computed simultaneously.

B. RISK OF STOCK-OUT

During depth computation, FMSO selects and uses a risk parameter value necessary to attain a stated effectiveness goal. The risk parameter influences the depth of each carried item and therefore the predicted effectiveness for the load over a specified time frame. The example below illustrates that the formula used by FMSO to determine risk does not accurately reflect the actual risk of a stock-out.

Using the example FILL computation in Chapter III, the following pertains:

Quarterly Average Demand = 100 units (Expanded demand)
Standard Deviation of Demand=50 units
Average Requisition Size = 20 units
Average No. of Requisitions/Qtr. = $\frac{100}{20} = 5$

FILL QTY. = 100 units (the qty. was rounded to a dollars worth of stock--unit price = $.01)
Risk of stock-out as calculated by FMSO = .02275

Assumptions:
(1) The AFS carries exactly 100 units of this item.
(2) The AFS is on-station for six months (two quarters).
(3) The deployed demand experienced by the AFS is equivalent to one-half of the QAD.
(4) The numbers of requisitions received in two nonoverlapping intervals are independent.
(5) The probability of receiving a requisition in a small interval is small, and is proportional to the length of the interval.
(6) The probability of two or more requisitions in a small interval is negligible.

Requisitions (demands) for items occur randomly, with an average of five requisitions per quarter. If Lambda (λ) represents the average of five requisitions per quarter and X represents the number of requisitions received, then the general expression for the probability of x requisitions becomes:

$$P(X) = \frac{e^{-\lambda}(\lambda)^X}{X!}, \quad (e = 2.71828)$$

The following summarizes the probabilities of X:

No. of requisitions	No. of units	P(X)	Cumulative Probability
X = 0	0	.00674	.00674
X = 1	20	.03369	.04043
X = 2	40	.08423	.12466
X = 3	60	.14037	.26503
X = 4	80	.17547	.4405
X = 5	100*	.17547	.61597
X = 6	120	.14622	.76219
X = 7	140	.10445	.86664
X = 8	160	.06528	.93192
X = 9	180	.03625	.96817
X = 10	200	.01813	.9863
X = 11	220	.00824	.9945

*Average number of units demanded during a 6-month (two quarters) deployment

The summary of probabilities illustrates that the risk (probability of a stock-out) during a quarter is (P (demand >100) = .38403) .38403 (1-.61597). It is understood that the FILL quantity computed by FMSO represents a minimum quantity to be carried onboard the AFS. In addition, as the AFS accumulates demand for the item, the quantity carried will increase in order to reduce the risk of stock-out. For example, if the AFS carried 200 units (double the FILL quantity), the risk of stock-out is .0137 (1-.9863). However, experience has shown that the initial FILL quantities generated by FMSO do not generally provide adequate protection from a stock-out situation. The importance of the initial FILL quantity is high-lighted when the AFS leaves CONUS and attempts to maintain a 90% FILL Net Effectiveness for a six month (two quarters) deployment period.

V. PROPOSED INVENTORY MODEL

A. INTRODUCTION

In the preceding chapter, the methods used by FMSO to develop an AFS FILL range and depth were discussed. The overriding factor in the development process is the availability of dollars. With this dollar constraint, FMSO has to develop an "inventory package" that best satisfies anticipated demands for a given amount of time. The problem is to select the "right mix" of items to be included in this package so that the number of unsatisfied demands or shortages is minimized.

The technique of static marginal analysis has been widely used to aid decision makers with resource allocation decisions similar to those required in the FILL determination [3]. This theory states that an efficient mix of productive inputs is that mix for which the ratio of marginal product to marginal cost is the same for each input. In other words, the composition of productive inputs should be arranged in such a way that the additional value (marginal product) obtained from the last dollar's worth (marginal cost) of each input should be equal. This theory has been and is used by managers as a tool to make decisions of production quantities and inventory levels.

In the case of determining inventory levels, six assumptions are made in static marginal analysis. Following

each of these assumptions listed below, a comment is made to illustrate how the assumptions fit AFS and FMSO operations.

(1) It is possible to make all adjustments in the compositions of the inventory prior to the period in which the inventory is to be used. FMSO can and does make inventory adjustments (both range and depth) prior to publishing the annual Atlantic FILL. The AFS, while in CONUS, can also make adjustments in the depth of items carried by setting levels (adjusting high and low limits) within authorized (COMNAVSURFLANT authorizes parameters to be used in level setting) parameters.

(2) Subsequent adjustments cannot be made during the period of use. After the AFS leaves CONUS, adjustments to the FILL are not impossible to make. However, once the AFS enters the Sixth Fleet, the personnel (stock control and cargo personnel) onboard are primarily concerned with making issues to the customer ships--not adjusting FILL quantities. Quarterly supplements produced by FMSO, delineating FILL adds and deletes, can be and usually are processed into the Master Record File of the AFS. However, because of the relatively long lead time experienced by the deployed AFS, the probability of obtaining all of these new items while deployed is very small.

(3) The demand for the items in the inventory is independent of the quantities stocked. The randomness of Sixth Fleet demand precludes an accurate estimate of future demand for loading purposes for a specific month [1].

(4) One kind of item cannot be used as a substitute for another kind of item in meeting the demands on the inventory. Substitutes within the FILL are possible. However, substitutions represent a small portion of the total issues made.

(5) There is no discontinuity or lumpiness (large differences in the range of items carried) in the possible inventory quantities. For the AFS, this assumption is well approximated because of the large size inventory. The range of items carried by the AFS usually numbers from 10,000 to 18,000.

(6) There is only one scarce resource which limits the size of the inventory. There are basically four scarce resources that the AFS has to contend with. First, the number of personnel onboard an AFS is a limiting factor. Secondly, storage space available onboard ship is limited. Thirdly, time availability in CONUS to order, load and record FILL items is another factor that limits the size of the inventory. The TYCOM, when making the range cut decisions, certainly has to keep these constraints in mind. However, the fourth and overriding scarce resource that FMSO has to deal with and the one that limits the size (quantities of items carried) of the FILL is money--the dollar constraint.

It is obvious that the assumptions of static marginal analysis do not fit completely. However, if the assumptions are even reasonably well met, as they appear to be in the case of the problem at hand, a traditional marginal analysis

offers the possibility of reaching better decisions of FILL composition than the present method. Furthermore, the marginal analysis method will determine range and depth simultaneously.

B. APPLICATION OF STATIC MARGINAL ANALYSES--A CONSTRAINED MULTIPLE ITEM PROBLEM

FMSO is faced with the difficult task of compiling a FILL of "n" different items. The only interaction between the items is assumed to be through the dollar (budget) constraint. This implies that the variables representing the demand for different items are independent random variables. This is a problem often referred to as the flyaway-kit (an Air Force mobility package) problem [4]. Reference 3 explains the importance of an Air Force mobility package and illustrates how marginal analysis was used to develop this package. The FILL (an AFS "sailaway-kit") is remarkably similar in its intended purpose to the Air Force mobility package. Therefore, the application of marginal analysis for FILL development is appropriate and will be discussed.

An AFS carries from 10,000 to 18,000 items (repair parts and consumables) based on 90 days anticipated Sixth Fleet usage [1]. The value of this inventory may exceed three million dollars [5]. The AFS, while deployed, is the first point of supply for all U. S. ships/units operating in the Sixth Fleet. The Sixth Fleet consists of approximately 40 ships, 20 aircraft squadrons and 21,000 people [1]. It is difficult to determine by unaided judgement the appropriate

quantity of each item to be included in the FILL. One problem is that each of the different kinds of items incurs a different cost when included in the FILL. Another problem is that there is statistical uncertainty as to the exact quantity of each item that will be required. For illustrative purposes, it may be useful to present first a brief example of how statistical uncertainty affects the problem; second, to describe how this statistical uncertainty can be used to measure marginal product, and, finally, how this plus the cost of including an item can be fitted into an analysis which equates the ratio of marginal product to marginal cost for every item. The left side of Table II shows the behavior of 46 items (the items were arbitrarily selected) which have an average demand, over a 24-month period, of one per month. Unfortunately, an item with an average demand of one part per month does not experience one demand per month. Some months there is no demand, sometimes there is one demand, sometimes two, and so on. These possible demands are shown in the first column of Table II. The second column shows the probability that each of the possible demands will occur. Thus there are only 368 chances out of 1000 that the demand for one of these parts would, in a particular month, be equal to the average demand, and there is a .632(1-.368) probability that the demand would be different. The particular probabilities shown in Table II are computed from the Poisson distribution (illustrated in the previous chapter). This distribution is

TABLE II

PROBABILITY OF DEMANDS

Items with an average demand of 1.0 per month

	Possible Demands	Probability	Expected Supply Results			
				Surplus	Consumption	Shortage
	0	.368				
	1	.368	Stock Zero	0	0	46
	2	.184				
46 Items	3	.061				
	4	.015				
	5	.003				
	6	.001	Stock one each	17	29	17

widely used in industrial quality control and inventory control and is particularly convenient distribution to use since its probabilities are completely determined by the average demand rate [3]. However, other probability distributions may be used.

The probabilities given in Table II are for a single item. Each of the individual 46 items having an average demand rate of one per month is subject to these same probabilities. The right hand part of Table II shows the expected supply results from all 46 items if the items are not stocked at all and if the average monthly demand (one per month) is stocked. Reference 3 illustrates how the expected surplus, consumption and shortage is calculated.

Table III illustrates 3,049 items that have an observed demand rate of .035 of a part per month. From Table III it is obvious that zero demand is overwhelmingly the most likely occurence. There are 965 chances in 1000 that an individual item will not be needed. Yet, if none of these items are stocked the expected number of supply shortages is 107. This is over twice as many shortages as the shortages occuring when none of the items with the higher demand rate (one per month) were stocked. In other words, the items with the lowest demands cause the largest number of shortages by not being in the package. This is because there are so many more items at these low demand rates, plus the fact that the relative uncertainty is greater at low demand rates. Because it is impossible to know which part

TABLE III

PROBABILITY OF DEMANDS

Items with an average demand of .035 per month

	Possible Demands	Probability	Expected Supply Results			
				Surplus	Consumption	Shortage
3,049 Items	0	.9656	Stock zero	0	0	107
	1	.03379				
	2	.00059	Stock one each	2,944	105	2

will be demanded, it would be necessary (minimizing expected stock-outs is the objective) to carry 3,049 parts, 2,944 of which are not used, in order to meet 107 out of 109 demands; and in spite of this surplus, 2 shortages are expected to occur. At a low demand rate like this, the surplus problem becomes acute, since the FILL is constrained by dollars. The problem is to minimize stock-outs (shortages) subject to the dollar constraint.

Let x be the demand for a given item and k the FILL quantity. The number of stock-outs for the item is then x-k if $x > k$ or 0 if $x \leq k$. Then the expected number of stock-outs with a FILL quantity of k is:

$$(SO) = \sum_{x=k+1}^{\infty} (x-k)\, p(x),$$ where p(x) is the probability of x demands.

The reduction in the number of expected stock-outs for the k+1 item is:

$$E_{k+1}(SO) - E_{k}(SO) = -\sum_{x=k+1}^{\infty} p(x).$$

This shows that the expected stock-out expression is convex (as the onhand quantity of an item increases, the expected number of shortages decreases at a decreasing rate). This convexity guarantees that the marginal analysis (marginal allocation) method produces optimal (minimum stock-outs subject to the constraint) solutions (see Reference 6).

Resource limitations are what makes all economic decision problems difficult, important, and interesting. The constraint on any productive activity can be, and usually is, ultimately expressed in terms of dollar cost. FMSO's

annual production of the Atlantic FILL is no exception. The budget constraint which FMSO has to work with is a very real limitation and is becoming increasing important in their operations. Since the FILL ("Sailaway Kit") consists of "n" items and is subject to a dollar limitation, the marginal analysis approach can consider both the probability that a part will be needed (its marginal product) and the dollars which must be given up in order to include it in the package (its marginal cost). The composition of the Sailaway Kit is then arranged according to static marginal analysis so as to obtain the maximum amount of supply protection from the available amount of money. The algorithm for marginal analysis is given below.

If the number of units stocked of item "i" is changed from ki-1 to ki, the expected reduction in stock-outs is Pi(ki), where $P_i(ki) = \sum_{x=k+i}^{\infty} p(x)$. The additional cost in adding this unit is (Ci), where Ci is the unit price of the item. Thus, the expected stock-out reduction per unit increase in dollars is: $\frac{Pi(ki)}{Ci}$. The procedure is then to progressively assign units to the item which yields the greatest reduction in expected stock-outs per unit increase in dollars. The first step is to compute: max $\frac{Pi(1)}{(i)}$.

If the maximum occurs for i=j set ki=1, and then compute: $\max_{i=j} \left[\frac{Pi(1)}{(Ci)}\right], \frac{Pj(2)}{Cj}$. The next unit is assigned to the item where this maximum occurs, etc. This is continued

until adding an additional unit would exceed the dollar constraint [4].

In order to illustrate this analytical approach, a simple problem is shown in which it is assumed that there are only four different items which are ordered by customer ships. The average demand and unit price of the four items are shown in Table IV. For example, item A has an average demand of one per month, and a unit price of $.50 while item B has an average demand of one per month and a unit price of $5.00.

The dollar limitation of this Sailaway Kit is $15.00. The problem is to select the combination of parts not exceeding the $15.00 limitation that will minimize the number of expected shortages. The computations that are performed to obtain the optimal selection of items to go into the Sailaway Kit are summarized in Table V. A measure called "marginal protection" is computed for each possible unit of each of the four items. This measures the additional product or value provided by each unit. The probability that one or more units of A will be demanded during the month is .632--refer to the probabilities illustrated in Table II. The probability that two or more units of A will be demanded during the month is .264--see Table II. The probability that three or more units of A will be demanded is .80, etc. The probability of the number of units demanded for items C and D are computed in the same manner as before from the Poisson distribution with a mean of .33.

TABLE IV

FOUR ITEM "SAILAWAY KIT"

Demand-Weight Data for Hypothetical Problem

Item	Average 30 Day Demand	Price
A	1.00	$0.5
B	1.00	5.0
C	0.33	2.0
D	0.33	0.1

TABLE V

MARGINAL PROTECTION

Probability of Needing Indicated Number of Units

Number of Units	(marginal protection) Item A	Item B	Item C	Item D
1	.632	.632	.283	.283
2	.264	.264	.045	.045
3	.080	.080	.005	.005
4	.019	.019		
5	.004	.004		
6	.001	.001		

While the first unit of B provides as much protection as the first unit of A, its dollar cost (unit cost) is ten times as much ($5.00 as compared to $.50). To allow for the effect of unit price, the value obtained from each unit of each item is expressed on a per dollar basis (i.e., the probability that each unit will be needed is divided by the marginal cost). This yields what is called the "marginal protection per dollar", and this is illustrated for each item in Table VI. For example, the marginal product of the first unit of A (.632) is divided by the unit price ($.50) and yields a marginal protection per dollar of 1.264 ($\frac{.632}{.5}$ = 1.264). Although the probability that the first unit of B will be needed is identical to that of A, its marginal protection per dollar is only a tenth (.126) as great because item B costs ten times as much as A.

C. SELECTION OF THE SAILAWAY KIT

Once the marginal protection per dollar has been calculated, the process of selecting the units to go into the Sailaway Kit is a relatively simple matter of ranking. All of the units are arranged in descending value of marginal protection per dollar as illustrated in Table VII. The first column represents the ranking of each unit of each item. The second column shows the marginal protection per dollar. The third column identifies the item and the unit of the item, and the fourth column gives the unit price of the item. The last column gives the cumulative dollar value,

TABLE VI

MARGINAL PROTECTION PER DOLLAR

Unit Numbers	Item A (0.5 Dollars)	Item B (5.0 Dollars)	Item C (2.0 Dollars)	Item D (0.1 Dollars)
1	1.264	.126	.142	2.827
2	.528	.053	.023	.451
3	.160	.016	.003	.050
4	.038	.004		.004
5	.008	.001		

TABLE VII

MARGINAL PROTECTION PER DOLLAR RANKING

Rank Order	Marginal Protection	Part and Unit	Price	Dollar Value
1	2.827	D-1	0.1	0.1
2	1.264	A-1	0.5	0.6
3	.528	A-2	0.5	1.1
4	.451	D-2	0.1	1.2
5	.160	A-3	0.5	1.7
6	.142	C-1	2.0	3.7
7	.126	B-1	5.0	8.7
8	.053	B-2	5.0	13.7
9	.050	D-3	0.1	13.8
10	.038	A-4	0.5	14.3*
11	.023	C-2	2.0	16.3
12	.016	B-3	5.0	21.3
13	.008	A-5	0.5	21.8
14	.004	B-4	5.0	26.8
15	.004	D-4	0.1	26.9
16	.003	C-3	2.0	28.9
17	.002	A-6	0.5	29.4
18	.001	B-5	5.0	34.4

*cut off point

which indicates the cost that has been incurred at any given cut-off point. If the dollar constraint in this example is $15.00, the maximum amount of protection could be obtained by stocking four units of A, two units of B, one unit of C, and three units of D. This selection would cost $14.30, which is within the dollar constraint.

The reason this simplified example does not use all of the money ($15.00) available is because there are only a few items and the unit prices are large in comparison to the total dollar constraint. In a real problem involving thousands of items using a dollar constraint as large as $2,000,000 or $3,000,000 it should be possible to arrive at a selection of items which has a total dollar value very close to the dollar constraint.

D. RESULTS OF COMPUTING A REALISTIC MOBILITY PACKAGE

This theory was applied, as described, to the design of a realistic full-sized Air Force mobility package [3]. This mobility package was computed from data on probability of demand distributions and unit weights (unit price was used in the Sailaway Kit) for each of the 15,000 eligible spare parts so as to use the 40,000 pound weight limit in optimal way. The resulting package scored very well when it was tested on paper against an operational situation of the type in which the package was designed to be used. It also performed better than the actual package used in the

operational exercise [3]. References 6 and 7 also cite successful application of marginal analysis to inventory problems.

The package selected in the manner described minimizes the expected number of shortages. It is also possible to extend the procedure to allow for the seriousness of the various shortages. The package is then designed so that the number of shortages weighted by essentialities is minimized. The rest of the marginal computation procedure then follows through as before. Furthermore, critical items (items that have to be included on the FILL) can be accommodated by use of technical overrides and by reducing the total dollar constraint by the dollar value of the critical items and applying marginal analysis to the remaining budget.

Additionally, it is possible to examine the reasonableness of the limitation (weight or dollar limitation) by simply showing what additional protection would be given if the limitation were increased by "n" units or what additional risk would be incurred if it were decreased by "n" units. Marginal analysis, therefore, represents a method of allocating limited resources among alternative uses.

VI. EVALUATION AND COMPARISON OF THE MODELS

A. TESTING PROCEDURES

For simplicity, an example of ten items (items A thru J) was generated in order to compare the present method of computing the FILL with the marginal analysis method. Table VIII lists the applicable parameters for each of the ten items. From these parameters, FILL quantities were computed using the two methods. Table IX exhibits the FILL quantities and total dollar value ($36.35) generated by using the present FMSO method. Table X, cut off at approximately the same dollar value ($36.45), exhibits the FILL quantities generated by using the marginal analysis method. Although the total dollar values of the two FILLs are approximately equal, the total quantities of the individual items are strikingly different. The FILL quantities of the ten items are shown below.

Item	FILL quantity present FMSO method	FILL quantity marginal analysis method
A	2	3
B	2	4
C	2	6
D	2	5
E	3	7
F	3	0
G	4	9
H	6	9
I	6	0
J	7	14
Total	37	57

TABLE VIII

TEN ITEM EXAMPLE PARAMETERS

Item	QAD	Standard Deviation(σ)	Unit/Price	Average Requisition Size
A	2.5	1.3093	.50	1
B	3.375	1.5019	.60	1
C	5.875	1.6744	.75	1
D	3.75	2.1213	.50	1
E	7.875	3.2266	1.00	1
F	9.125	3.0443	1.75	1
G	6.625	2.6693	.25	1
H	13.75	3.8452	1.50	1
I	13.875	3.3991	2.00	1
J	10.625	5.8539	.20	1

TABLE IX

PRESENT FMSO METHOD FILL QUANTITIES

Item	$\frac{FIRL}{4}$ = FILL	FILL QTY	$ Value	Cumulative $ Value
A	$\frac{3.75}{4}$=.9375	2*	1.00	1.00
B	$\frac{5.338}{4}$=1.335	2*	1.20	2.20
C	$\frac{9.776}{4}$=2.444	2*	1.50	3.70
D	$\frac{6.742}{4}$=1.685	2*	1.00	4.70
E	$\frac{13.669}{4}$=3.417	3*	3.00	7.70
F	$\frac{13.874}{4}$=3.468	3*	5.25	12.95
G	$\frac{14.351}{4}$=3.587	4*	1.00	13.95
H	$\frac{23.451}{4}$=5.863	6*	9.00	22.95
I	$\frac{22.311}{4}$=5.578	6*	12.00	34.95
J	$\frac{27.553}{4}$=6.888	7*	1.40	36.35

*Quantities rounded to the nearest whole number/dollars worth of stock

TABLE X

MARGINAL PROJECTION PER DOLLAR RANKING

Marginal Projection /$	Item	U/P	$	Marginal Projection /$	Item	U/P	$
4.9998785	J-1	.20	.20	1.1163836	C-4	.75	11.30
4.9985875	J-2	.20	.40	1.0923535	B-3	.60	11.90
4.9917291	J-3	.20	.60	1.0324628	D-4	.50	12.40
4.967439	J-4	.20	.80	.99961987	E-1	1.00	13.40
4.9029183	J-5	.20	1.00	.99662634	E-2	1.00	14.40
4.7658119	J-6	.20	1.20	.98483931	E-3	1.00	15.40
4.5230194	J-7	.20	1.40	.95389836	E-4	1.00	16.40
4.154495	J-8	.20	1.60	.93048307	C-5	.75	17.15
3.9946928	G-1	.25	1.85	.9261083	J-14	.20	17.35
3.959533	G-2	.25	2.10	.91237194	A-3	.50	17.85
3.843066	G-3	.25	2.35	.89393716	G-9	.25	18.10
3.6650485	J-9	.20	2.55	.89298336	E-5	1.00	19.10
3.5858682	G-4	.25	2.80	.79704223	E-6	1.00	20.10
3.1598842	G-5	.25	3.05	.72694723	B-4	.60	20.70
3.0872298	J-10	.20	3.25	.71204995	C-6	.75	21.45
2.5954554	G-6	.25	3.50	.6711195	E-7	1.00	22.45
2.4732972	J-11	.20	3.70	.66666595	H-1	1.50	23.95
1.972232	G-7	.25	3.95	.66665617	H-2	1.50	25.45
1.9529644	D-1	.50	4.45	.66658888	H-3	1.50	26.95
1.8802943	J-12	.20	4.65	.66628047	H-4	1.50	28.45
1.8358297	A-1	.50	5.15	.66522033	H-5	1.50	29.95
1.7765808	D-2	.50	5.65	.66230495	H-6	1.50	31.45
1.6096363	B-1	.60	6.25	.65562385	H-7	1.50	32.95
1.4458617	D-3	.50	6.75	.6449013	D-5	.50	33.45
1.425404	A-2	.50	7.25	.64250029	H-8	1.50	34.95
1.417159	B-2	.60	7.85	.61994415	H-9	1.50	36.45 *
1.3823955	G-8	.25	8.10	.60042835	J-15	.20	36.65
1.3552396	J-13	.20	8.30	.58548339	H-10	1.50	38.15
1.3295883	C-1	.75	9.05	.57136634	F-1	1.75	39.90
1.3075859	C-2	.75	9.80	.57079845	F-2	1.75	41.65
1.2429542	C-3	.75	10.55	.56820747	F-3	1.75	43.40

*cut-off point

The key question remaining unanswered is, "which one of these two FILL packages will yield the fewest number of shortages (units short) when tested against Sixth Fleet (deployed) demand?". To answer this question the two FILL packages were tested over a period of 12 quarters or six 6-month deployments. Current demand (both expanded and deployed) was obtained from FMSO--see Table X9. Random numbers were then generated, using the exponential distribution, to simulate the deployed demand for a 12-quarter period. Table XII shows the demands generated in each of the 12 quarters.

B. TEST RESULTS

The simulated deployed demand, Table XII, was compared to the FILL quantities generated by the two methods over six 6-month periods. Table XIII displays the results of the comparison. The present FMSO method experienced 190 total units short, 11 total units surplus, and a units effectiveness of approximately 53% ($\frac{211 \text{ issues}}{401 \text{ requirements}}$ = .526). The marginal analysis method experienced 160 total units short, 101 total units surplus, and a units effectiveness of approximately 60% ($\frac{241 \text{ issues}}{401 \text{ requirements}}$ = .6009). With about the same dollar investment ($36.45 as compared with $36.35), the marginal analysis method reduced the number of shortages (units short), over the 36-month period, by approximately 16%.

In summary, this small example illustrates the value of marginal analysis as a tool to aid in the selection of items

for the AFS inventory package ("Sailaway Kit"). Although this represents only one verification for the use of marginal analysis, the fact that it gave better results than did the present method is worthy of note.

TABLE XI

FMSO DEMAND DATA

Month/ Year	Expanded Demand	Deployed Demand	Deployed Demand as % of Expanded
March 78	71,839	24,782	34.5%
April 78	91,213	35,670	39.1%
May 78	67,475	22,946	34.0%
June 78	86,072	35,136	40.8%
July 78	108,660	38,736	35.6%
August 78	85,995	30,070	34.9%
Total	511,254	187,347	36.6%

TABLE XII

DEMANDS BY QUARTER

	Quarters												
Item	1	2	3	4	5	6	7	8	9	10	11	12	Total
A	1	0	0	4	1	1	0	0	0	0	2	2	11
B	0	1	1	1	2	1	2	1	1	0	0	2	12
C	5	4	4	5	2	2	6	6	1	0	3	2	40
D	1	0	2	1	2	1	0	4	1	3	1	1	17
E	6	1	2	1	3	4	4	5	5	4	2	3	40
F	0	5	1	7	3	7	11	3	5	5	8	2	57
G	2	3	4	1	1	7	4	1	2	4	4	2	35
H	10	7	4	2	7	7	10	3	3	3	6	7	69
I	10	3	6	2	1	4	5	5	7	7	7	7	64
J	5	6	1	5	6	5	6	4	4	5	5	4	56

TABLE XIII

TEST RESULTS

Item		Present FMSO Method							Marginal Analysis Method					
A	Quantity Carried..	2	2	2	2	2	2	...	3	3	3	3	3	3
	Requirement.......	1	4	2	0	0	4	...	1	4	2	0	0	4
	Units short.......	0	2	0	0	0	2	...	0	1	0	0	0	1
	Units surplus.....	1	0	0	2	2	0	...	2	0	1	3	3	0
B	Quantity Carried..	2	2	2	2	2	2	...	4	4	4	4	4	4
	Requirement.......	1	2	3	3	1	2	...	1	2	3	3	1	2
	Units short.......	0	0	1	1	0	0	...	0	0	0	0	0	0
	Units surplus.....	1	0	0	0	1	0	...	3	2	1	1	3	2
C	Quantity Carried..	2	2	2	2	2	2	...	6	6	6	6	6	6
	Requirement.......	9	9	4	12	1	5	...	9	9	4	12	1	5
	Units short.......	7	7	2	10	0	3	...	3	3	0	6	0	0
	Units surplus.....	0	0	0	0	1	0	...	0	0	2	0	5	1
D	Quantity Carried..	2	2	2	2	2	2	...	5	5	5	5	5	5
	Requirement.......	1	3	3	4	4	2	...	1	3	3	4	4	2
	Units short.......	0	1	1	2	2	0	...	0	0	0	0	0	0
	Units surplus.....	1	0	0	0	0	0	...	4	2	2	1	1	3
E	Quantity Carried..	3	3	3	3	3	3	...	7	7	7	7	7	7
	Requirement.......	7	3	7	9	9	5	...	7	3	7	9	9	5
	Units short.......	4	0	4	6	6	2	...	0	0	0	2	2	0
	Units surplus.....	0	0	0	0	0	0	...	0	4	0	0	0	2
F	Quantity Carried..	3	3	3	3	3	3	...	0	0	0	0	0	0
	Requirement.......	5	8	10	14	10	10	...	5	8	10	14	10	10
	Units short	2	5	7	11	7	7	...	5	8	10	14	10	10
	Units surplus.....	0	0	0	0	0	0	...	0	0	0	0	0	0
G	Quantity Carried..	4	4	4	4	4	4	...	9	9	9	9	9	9
	Requirement.......	5	5	8	5	6	6	...	5	5	8	5	6	6
	Units short.......	1	1	4	1	2	2	...	0	0	0	0	0	0
	Units surplus.....	0	0	0	0	0	0	...	4	4	1	4	3	3
H	Quantity Carried..	6	6	6	6	6	6	...	9	9	9	9	9	9
	Requirement.......	17	6	14	13	6	13	...	17	6	14	13	6	13
	Units short.......	11	0	8	7	0	7	...	8	0	5	4	0	4
	Units surplus.....	0	0	0	0	0	0	...	0	3	0	0	3	0
I	Quantity Carried..	6	6	6	6	6	6	...	0	0	0	0	0	0
	Requirement.......	13	8	5	10	14	14	...	13	8	5	10	14	14
	Units short.......	7	2	0	4	8	8	...	13	8	5	10	14	14
	Units surplus.....	0	0	1	0	0	0	...	0	0	0	0	0	0
J	Quantity Carried..	7	7	7	7	7	7	...	14	14	14	14	14	14
	Requirement.......	11	6	11	10	9	9	...	11	6	11	10	9	9
	Units short.......	4	0	4	3	2	2	...	0	0	0	0	0	0
	Units surplus.....	0	1	0	0	0	0	...	3	8	3	4	5	5

							Total							Total
Total Quantity....	37	37	37	37	37	37	222	57	57	57	57	57	57	342
Total Requirement.	70	54	67	80	60	70	401	70	54	67	80	60	70	401
Total units short.	36	18	31	45	27	33	190	29	20	20	36	26	29	160
Total surplus.....	3	1	1	2	4	0	11	16	23	10	13	23	16	101

VII. CONCLUSIONS AND RECOMMENDATIONS

The marginal analysis method of developing inventory packages appears to be superior to the method presently being used by the Fleet Material Support Office. FMSO is faced with the difficult task of computing the best inventory package within certain dollar constraints. Within the present method, the TYCOM, who may or may not be aware of the dollar constraint, makes a somewhat arbitrary range selection decision. The quantities of each of these items, within this selected range, must then be determined and the total value must be equal to or less than the dollar constraint. Several iterative computations (changing the value of Lambda) may be required before the "right quanitites" are generated. With marginal analysis, only one computation would be required. The range and depth for the items are computed simultaneously and once the cumulative total dollar value equals the dollar constraint (as an example: the dollar value of a "Sailaway Kit" for a given Combat Stores Ship), the computational effort can be terminated. Technical overrides can continue to be applied to those items that must be included in the "Sailaway Kit". As noted earlier, items may be weighted according to their essentiality. Marginal analysis could be restricted to those items that have relatively low quarterly average demand. It could be used for certain categories of items, such as NSA-NER or APA.

From a practical point of view, the results of the research confirm the superiority of marginal analysis as applied against this small example of items. The present method used by FMSO resulted in a units effectiveness of 53% while the marginal analysis method, with approximately the same dollar investment, yielded a units effectiveness of 60%.

This example of ten items verified that the marginal analysis method provides an AFS with a base of items that will yield fewer shortages over a period of time. It is recommended that the Naval Supply Command give serious consideration to the use of marginal analysis as a "Sail-away Kit" generator. It is recommended that further study, using larger samples, be initiated. As discussed in references 3 and 4, marginal analysis is by no means a substitute for judgement, but it can be, and should be, used as an inventory aid in applying it.

APPENDIX A

ACRONYMS

AFS.........................Combat Stores Ship

APA.........................Appropriated Purchases Account

CARGO.......................Consolidated Requisitioning Guide-Overseas

COMNAVSURFLANT..............Commander Naval Surface Forces Atlantic

COMNAVSUPSYSCOM.............Commander Naval Supply Systems Command

CONUS.......................Continental United States

ER..........................Equipment Related

FILL........................Fleet Issue Load List

FIRL........................Fleet Issue Requirements List

FMSO........................Fleet Material Support Office

HULL........................High Usage Load List

MLSF........................Mobile Logistics Support Force

NAS.........................Naval Air Station

NAVRESO.....................Navy Resale Systems Office

NSA.........................Navy Stock Account

NER.........................Non-Equipment Related

NSC.........................Naval Supply Center

NSD.........................Naval Supply Depot

OPNAV.......................Operations Navy

PLO.........................A Project Code identifying FILL ashore

POS........................Peacetime Operating Stocks

PWRR.......................Prepositioned War Reserve Requirement

QAD........................Quarterly Average Demand

SAC........................Special Accounting Class

TYCOM......................Type Commander

APPENDIX B

EQUIPMENT-RELATED ITEM IDENTIFICATION

The following is a list of FSGs (Federal Supply Groups). An NSA item assigned with any one of the FSGs marked with an asterisk (*) is coded as an equipment-related item in the FIRL/FILL process. All other NSA items are coded as non-equipment related.

FSG	TITLE
*10	Weapons
11	Atomic ordnance
*12	Fire control equipment
13	Ammunition and explosives
*14	Guided missiles
15	Aircraft and airframe structural components
16	Aircraft components and accessories
*17	Aircraft launching, landing, and ground handling equipment
18	Space vehicles
*19	Ships, small craft, pontoons, and floating docks
*20	Ship and marine equipment
21	Unassigned
22	Railway equipment
23	Motor vehicles, trailers, and cycles
24	Tractors
25	Vehicular equipment components
26	Tires and tubes
27	Unassigned
*28	Engines, turbines, and components
*29	Engine accessories
*30	Mechanical power transmission equipment
*31	Bearings
32	Woodworking machinery and equipment
33	Deleted
*34	Metal working machinery
35	Service and trade equipment
36	Special industry machinery
37	Agricultural machinery and equipment
38	Construction, mining, excavating, and highway maintenance equipment
39	Materials handling equipment
40	Rope, cable, chain, and fittings
*41	Refrigeration and air conditioning equipment
*42	Fire fighting, rescue, and safety equipment

*43 Pumps and compressors
*44 Furnace, steam plant, and drying equipment; and nuclear reactors
*45 Plumbing, heating, and sanitation equipment
*46 Water purification and sewage treatment equipment
47 Pipe, tubing, hose, and fittings
*48 Valves
49 Maintenance and repair shop equipment
50 Unassigned
51 Hand tools
52 Measuring tools
53 Hardware and abrasives
54 Prefabricated structures and scaffolding
55 Lumber, millwork, plywood, and veneer
56 Construction and building materials
57 Unassigned
*58 Communication equipment
*59 Electrical and electronic equipment components
60 Unassigned
*61 Electric wire, and power and distribution equipment
62 Lighting fixtures and lamps
*63 Alarm and signal systems
64 Unassigned
65 Medical, dental, and veterinary equipment and supplies
*66 Instruments and laboratory equipment
67 Photographic equipments
68 Chemicals and chemical products
69 Training aids and devices
70 Unassigned
71 Furniture
72 Household and commercial furnishings and appliances
73 Food preparation and serving equipment
74 Office machines and data processing equipment
75 Office supplies and devices
76 Books, maps, and other publications
77 Musical instruments, phonographs and home-type radios
78 Recreational and athletic equipment
79 Cleaning equipment and supplies
80 Brushes, paints, sealers and adhesives
81 Containers, packaging, and packing supplies
82 Unassigned
83 Textiles, leather and furs
84 Clothing and individual equipment
85 Toiletries
86 Unassigned
87 Agricultural supplies
88 Live animals
89 Subsistence

90 Unassigned
91 Fuels, lubricants, oils, and waxes
92 Unassigned
93 Nonmetallic fabricated materials
94 Nonmetallic crude material
95 Metal bars, sheets and shapes
96 Ores, minerals, and their primary products
97 Unassigned
98 Unassigned
99 Miscellaneous (2)

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