DEVELOPMENT OF A TIME-WEIGHTED, ESSENTIALITY-WEIGHTED SHORTAGE COST (λE)

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Abstract

Currently, the Navy uses shortage costs which are fixed over a large range of items and are independent of the item's average acquisition price, average acquisition time and military essentiality. Today's shortage costs are imputed costs based on a given budgetary goal. This analysis evaluates procedures designed to measure the actual time-weighted, essentiality-weighted shortage costs (λE). One of the methods evaluated for computing shortage costs is based on the item's average acquisition price, since this is the minimum measure of how much the Navy is willing to spend to avoid a shortage. Shortage costs are also computed using the cost to operate and support a ship. This method is based on the assumption that the value of a ship's primary mission capabilities is equivalent to the amount of money the Navy is willing to spend to operate and support the ship. Under this method, item shortage costs are computed as a percentage of the ship's operating and support costs based upon that item's essentiality to the ship's primary mission. This report analyzes alternative techniques to measure the λE, recommends a specific method and discusses issues related to the implementation of the recommendation.

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ESSENTIALITY-WEIGHTED
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TABLE OF CONTENTS

Executive Summary

1. Background. Historically, the actual shortage costs associated with military supply systems have not been measured. The current Navy inventory model seeks to minimize total variable costs, exclusive of the shortage cost, subject to a constraint that the percentage of requisitions satisfied equals a specified value. In practice, the model is used to maximize the percentage of requisitions satisfied given a predetermined investment constraint. Thus, the shortage cost is determined implicitly based on budgetary goals/constraints. Each item has the same shortage cost regardless of the item's average acquisition price, average acquisition time or military essentiality.

2. Objective. To determine and document a generalized procedure for calculating shortage cost for wholesale items using Visibility and Management of Support Costs (VAMOSC) data instead of the management-determined/budget constrained values used today.

3. Technical Approach. This study computed shortage cost as a fixed cost plus a variable cost. The fixed cost was measured as the sum of the administrative cost to order, the administrative cost to backorder and the cost of a spot buy. The variable cost was computed by multiplying the cost associated with being out of stock of the item by the length of time the item was backordered. The only difference in the shortage cost calculations analyzed in this study was the manner in which the "cost" of being out of stock for the item was selected for the variable cost segment of the shortage cost.

Methods of computing the variable cost differed in that one was based on the item's average acquisition price while others were based on the ship's operating and support costs. Using the average acquisition price as a measure of the shortage cost recognizes the average acquisition price as a measure of the minimum amount the Navy is willing to spend to avoid a shortage. The use of a ship's operating and support costs as a measure of shortage cost is based on the assumption that the value of a ship's primary mission capabilities is equivalent to the amount of money the Navy is willing to spend to operate and support the ship. Items which are essential (in varying degrees) to the ship's primary mission have a shortage cost that equals a percentage (depending on the essentiality) of the ship's operating and support costs.

4. Findings. The shortage costs based on the items average acquisition price averaged $22K and the corresponding acceptable risk of stockout was 6%. Five other methods of computing a time-weighted, essentiality-weighted shortage cost (λE) considered item essentiality and the ship's operating and support costs (VAMOSC data). These methods differed in their calculation of λE based upon the number of different ship types the item was on, those ships' operating and support costs and the number of applications on each ship. These five methods yielded similar results and the study showed that a simple average of the different ship's costs was appropriate. Known as the Average method, the λEs averaged $21K, $4.3M, $14.3M and $18.6M for items with essentiality of 1, 2, 3 and 4, respectively. The corresponding acceptable risks of stockout were 6% for essentiality 1 items and less than 1% for all other items. The λEs SPCC currently use for this material range from $.015 to $1,250. Comparing these costs, the current shortage costs appear to be orders of magnitude too small.

The impact of λE on cost and material availability was evaluated under three scenarios. First, the λE value computed as described above were compared to the current method of a fixed shortage cost for all items. Using the Average method of computing λE increases the Supply Material Availability (SMA) 12 percentage points and decreases ADD 47 days for a 127% increase in inventory investment. Since the average method of computing λE yields 97.4%

SMA, the second scenario used a percentage of the computed λE to yield an 85% SMA. Under the constant 85% SMA comparison, the VAMOSC based λE increased inventory investment 18%. In addition, the VAMOSC based λE provided better SMA and lower Average Days Delay (ADD) for the more essential items. Under the VAMOSC based λE, the SMA drops from 77 to 38% (ADD increases from 97 to 240 days) for essentiality 1, SMA remains constant at 86% (ADD decreases from 55 to 48 days) for essentiality 2, SMA improves from 86 to 90% (ADD decreases from 53 to 29 days) for essentiality 3 and SMA improves from 84 to 92% (ADD decreases from 69 to 39 days) for essentiality 4. The third scenario used an even smaller percentage of the VAMOSC based λE so that inventory investment would equal current investment. Under this comparison, the VAMOSC based λEs are drastically reduced (by a factor of .9983) to a level which is comparable to current shortage costs. This evaluation technique shows the Average Method lowers the overall SMA by 10 percentage points and adds 6.5 days to ADD. However, the VAMOSC based λEs do reduce the ADD for essentiality 4 (from 112 to 86) and maintain the same ADD (103) for essentiality 3 while increasing ADD significantly for essentiality 2 (43 days) and essentiality 1 (89 days).

5. Conclusions. The Average method for determining λE for SPCC items should be implemented during resystemization. Implementation of this method will require a new Data Element Number (DEN) for λE and a computer program to calculate and annually update the λE value for each National Item Identification Number (NIIN).

Since implementation of the Average method to calculate λE is a long range effort, SPCC should in the short term use the mean of the actual λE values calculated in this study by the Average method in lieu of the budget constrained values used today. The shortage cost values in Uniform Inventory

Control Program (UICP) could then vary by essentiality since the mean calculated using the Average method varies by essentiality. The average λE values calculated using the Average method to obtain 85% SMA are approximately \$30, \$6,000, \$20,000 and \$26,000 for items with essentiality of 1, 2, 3 and 4, respectively. Using these values for λE in UICP would achieve a 30% reduction in weighted ADD at a cost of \$194M.

6. Further Efforts. The methods evaluated in this study assume that an item has a single IMEC value even when the item has multiple applications. Yet an item can appear on more than one equipment or more than one ship resulting in multiple applications per item. Reference 4 of Appendix A proposed to average the IMEC values of all applications to determine a single essentiality value for the item. This study proposes to average the VAMOSC data for the ships the items appear on to determine a single ship's cost and to use the average IMEC value and the average ship's cost to determine the shortage cost value for the item. An alternative method of calculating λE for items with multiple applications, which should be evaluated, is to develop a shortage cost for each application of the item based on the application's IMEC value and VAMOSC data. A unique shortage cost for the item could then be determined by calculating a simple average of the application shortage costs. Therefore, instead of determining the shortage costs based on two averages (for the IMEC value and for the ship's cost) the shortage cost would be based on one average (across the application shortage costs).

Because the operating and support costs are not available for equipments, a percentage of the ship's operating and support costs was used for those items which were neither most or least essential (items with essentiality values of 2 or 3). Using equipment cost data to calculate λE for items with essentiality 2 or 3 should be evaluated if the data becomes available.

7. Recommendations.

a. Long Range. FMSO recommends implementation of the Average method to determine shortage costs for SPCC items.

b. Short Range. FMSO recommends that SPCC use the average λE values found in Appendix E, which vary by essentiality, in UICP in place of the budget constrained shortage cost values used currently.

c. Further Efforts. FMSO recommends follow-on analysis in the following areas:

(1) Develop a shortage cost for each application of an item. Calculate the average of the application shortage costs instead of two averages (one for IMEC values and a second for ship operating costs).

(2) Use equipment cost data to calculate the shortage cost for items with essentialities of 2 and 3 if such data becomes available.

I. INTRODUCTION

Reference (1) of Appendix A establishes a Department of Defense (DOD)-wide policy for determining the order quantity (Q) and reorder level (RL) for consumable items at the Inventory Control Points (ICPs). The instruction states the objective for determining the order quantity and reorder level is to "minimize the total variable order and holding costs subject to a constraint on time-weighted, essentiality-weighted requisitions short". According to reference (1) of Appendix A, the Total Variable Cost (TVC) equation should include shortage cost as shown below:

$$TVC = OC + HC + \lambda E(BO/S)$$

where

OC = order costs

HC = holding costs

λ = shortage cost per requisitions short per year

E = item essentiality

BO = expected number of backorders at any given point in time

S = requisition size

Currently, the Navy does not measure the cost of a shortage. The Uniform Inventory Control Program (UICP) levels calculation (reference (2) of Appendix A) assigns the same shortage cost value to an entire Cognizance Symbol (Cog) of items. The specific value is determined to maximize the percentage of requisitions satisfied given a predetermined investment constraint. Thus, the shortage cost is an implicit cost based on budget limitations. Each item has the same shortage cost regardless of the item's average acquisition price, average acquisition time or military essentiality. UICP uses these shortage costs to compute the acceptable risk of stockout as illustrated in the formula below.

$$\rho = \frac{SIC^*}{SIC^*+\lambda E}$$

where

ρ = acceptable risk of stockout

S = average requisition size

I = holding cost

C* = average acquisition price

λ = shortage cost per requisitions short per year

E = item essentiality

The acceptable risk of stockout influences the safety level calculation. Therefore, shortage costs affect safety levels such that larger shortage costs produce greater safety levels.

Reference (3) of Appendix A initiated this study to analyze alternative methods for determining time-weighted, essentiality-weighted shortage costs (λE). The alternative methods calculate realistic shortage costs by measuring how much the Navy is willing to spend to avoid a shortage. The analysis considered the average acquisition price, the military essentiality and Visibility and Management of Support Costs (VAMOSC) in calculating shortage costs.

Current UICP levels computations include an item essentiality factor. However, differentiation among essentialities does not exist because all items managed by an ICP are assigned the same item essentiality value. Recently, Item Mission Essentiality Codes (IMECs) were proposed and are currently being developed for Navy Ships Parts Control Center (SPCC) items. An IMEC is assigned to every application of an item and represents the importance of the item to the mission of the military unit upon which the item is installed. One overall item essentiality value is assigned to an item based on the item's IMEC values. The proposed methods of calculating shortage costs include item essentiality through the concept of IMEC values. Since IMEC values are only available for SPCC items, the analysis was performed for SPCC items. More information concerning the development of IMECs and various techniques of assigning one essentiality value to an item regardless of the various IMECs assigned to the item, can be obtained in reference (4) of Appendix A.

The cost incurred to the Navy for backordering an item was based on either the item's average acquisition price or on the operating and support costs for the ships the item is found on. The average acquisition price was used as a measure of the minimum amount the Navy is willing to spend to avoid a shortage because the Navy was willing to pay this amount to obtain the item. If the lack of an item causes an equipment to become inoperable or results in the loss of primary mission capabilities of a ship, the cost incurred to the Navy is the equipment's or ship's Life Cycle Cost (LCC). The equipment's or ship's LCC was measured as the operating and support cost of the equipment or ship, respectively. VAMOSC data, which represents operating and support costs of individual Navy ships for a fiscal year, determined the cost of an equipment and ship.

The procedures used in this analysis to develop shortage costs measure the value of the item to the Navy and use the item value as the item shortage cost. Thus, each item has a unique and explicit shortage cost. These procedures are in stark contrast to today's assignment of the same shortage cost to an entire Cog of items. The procedures also differ in their derivation of the shortage cost, since today's costs are implicit based on arbitrary budgetary goals.

II. TECHNICAL APPROACH

A. <u>GENERALIZED PROCEDURE FOR DETERMINING SHORTAGE COST</u>. According to reference (5) of Appendix A, the shortage cost consists of a fixed (π) and variable cost ($\hat{\pi}t$).

$$\lambda E = \pi + \hat{\pi}t$$

where

π = administrative order cost + administrative backorder cost + spot buy cost (if applicable).

$\hat{\pi}t$ = (cost)(LT*).

In this study, the fixed cost equals the sum of the administrative cost to order, the administrative cost to backorder and the cost to spot buy. Spot buys are made only for high priority material. The administrative cost to order (represented by Data Element Number (DEN) V043) currently equals $570.00 as specified in reference (6) of Appendix A. The administrative cost to backorder consists of the cost to review the list of backordered items as advised by reference (7) of Appendix A. The cost to review the list of backordered items was determined by multiplying the average number of hours required per month to review the backorder list, by the average hourly wage of the item managers. This product was divided by the average number of items reviewed per month to compute an average cost to review an item over the period of a month. Analyzing data supplied by SPCC resulted in an average cost to review an item per month of $.26. The average cost to review an item per month was then multiplied by each item's procurement leadtime in months resulting in the administrative cost to backorder. The cost to spot buy included the premium portion of the item's price and additional paperwork. The cost to spot buy was measured as 33% of the item's unit price which coincides with the manner in which SPCC determines spot buy costs.

The variable cost is defined as the cost associated with being out of stock of the item for the backorder period. The variable cost comprises the largest portion of the shortage cost for this study. The length of time the item is backordered was measured as a weighted average of procurement leadtime and repair Turn-Around-Time (TAT). The percent of the item's demand satisfied by procurement was multiplied by the item's procurement leadtime, and the percent of the item's demand satisfied through repair was multiplied by the item's repair TAT. The sum of these products represents the average length of time (in days) the item was backordered and is identified as LT*.

$$LT^* = (1-B/D)\ LT + (B/D)\ T$$

where

B = quarterly Ready-For-Issue (RFI) regenerations forecast (DEN B074A)

D = quarterly demand forecast (DEN B074)

LT = procurement leadtime forecast (DEN B011A)

T = repair problem average TAT forecast (DEN B012F)

Appendix B contains the backorder period (LT*) statistics which were computed and used in this study.

B. ALTERNATIVE METHODS USED TO CALCULATE THE VARIABLE COST SEGMENT. This study analyzed six alternative methods of calculating shortage cost based on the equations shown above. The only difference in the proposed methods is the procedure for calculating the "cost" used in the variable cost segment of the shortage cost. This study selected the "cost" from two sources of information: average acquisition price and VAMOSC data. The methods used to compute these costs are described below and examples which illustrate the concepts are provided in Section C.

1. Average Acquisition Price. One of the six methods evaluated in this analysis used the replacement and repair cost of the item to calculate the variable cost segment of the shortage cost. This method was based on the concept that the shortage cost is dependent on the cost the Navy is willing to pay for the item. This technique is identified as the Acquisition Price Method throughout the study. The Navy's cost was computed as a weighted average of the item's replacement and repair prices. The percentage of the item's demand satisfied through procurement was multiplied by the replacement price, and the percentage of the item's demand satisfied through repair was multiplied by the repair price. The sum of these products represents the average cost the Navy pays for the item and is identified as C*.

$$C^* = (1-B/D)\ C + (B/D)\ C'$$

where

C = replacement price (DEN B055)

C' = repair price (DEN B055A)

The square root of this cost was used in the variable cost equation as described in reference (5) of Appendix A. Thus, the variable cost ($\hat{\pi}t$) for the Acquisition Price Method equals ($\sqrt{C^*}$) (LT*). Summing the variable cost with the fixed cost determines the shortage cost of the item. Therefore, this method determines shortage costs based on the price of the items and ignores item essentiality. For items with similar leadtimes and TATs, the more expensive item receives more protection regardless of the essentiality of the item.

2. VAMOSC Data. The remaining five methods focus on computing a time-weighted, essentiality-weighted shortage cost (λE). The shortage cost was computed as a function of VAMOSC data, item essentiality and the backorder period. (The Input Section of this document describes VAMOSC data in more detail.) For items which cause total loss of the primary mission of a ship, the cost to the Navy of being short per day is the ship's life cycle cost per day. Since VAMOSC data represents the operating and support costs for a ship for a year, the VAMOSC values were divided by 365 to obtain the operating and support costs for a ship for a day. However, including 100% of the VAMOSC data implies the ship is incapable of performing its primary mission. As explained by the item essentiality definitions obtained from reference (8) of Appendix A, and listed in TABLE I, only a stockout of an item with an essentiality of 4 renders a ship incapable of performing its primary mission. Therefore, items with an essentiality of 4 use 100% of the VAMOSC data in computing shortage cost while items with lower essentialities use only a portion of the VAMOSC data because the ship's primary mission capabilities are degraded to some lesser extent or not at all. (Equipment costs would be used for items with essentiality of 2 and 3, however, this information is not available.) TABLE I below also shows the percentage of the VAMOSC data which is used in computing shortage costs for items with essentiality of 4, 3 or 2. (The percentages used for essentialities of 2, 3 and 4 were suggested in reference (9) of Appendix A and are consistent with the maintenance community's use of relative weights for Casualty Reports (CASREPs) C2, C3 and C4.) Shortage cost for items with

essentiality of 1 was always computed by the Acquisition Price Method because any percentage of the VAMOSC data was deemed too large for such low priority items.

TABLE I

Percent of VAMOSC Cost Data Associated with Item Essentiality

Item Essentiality	% of VAMOSC Data	Definition
4	100%	Loss of primary mission capability
3	50%	Severe degradation of primary mission capability
2	10%	Loss of secondary mission capability
1	Acquisition Price Method	Minor mission impact

As in the Acquisition Price Method, the shortage cost was then priced out over the backorder period. Therefore, the variable cost in the five remaining proposed methods for items with essentiality of 4, 3 and 2 was computed using the following equation:

$$\hat{\pi}t = \left(\frac{VAM}{365}\right)(PV)(LT^*)$$

where

VAM = VAMOSC Cost

PV = percent of VAMOSC cost data based upon TABLE I essentialities

Since the same item may be used on several different ships, an item can be associated with several VAMOSC values. The only difference in these five methods was the manner in which a VAMOSC value was selected for the variable cost segment of the shortage cost. The following method descriptions pertain only to items with essentiality values of 4, 3 and 2, because shortage costs for items with essentiality of 1 are always computed using the square root of C* under the Acquisition Price Method.

a. Lowest Method - Examine all VAMOSC values for the ships (Unit Identification Codes (UICs)) on which the item was installed and select the lowest value.

b. Average Method - Sum the VAMOSC values for each UIC the item was installed on and divide by the number of UICs on which the item was installed to obtain an average cost.

c. Weighted Average Method - Multiply each UIC cost by the UIC population; i.e., the number of times the item appeared on the ship. Divide the sum of these values by the sum of all UIC populations to obtain a weighted average.

d. Mode Method - Examine the VAMOSC data for the UICs on which the item appeared and select the value which appears most frequently (mode). If there were multiple modes, the highest mode was chosen.

e. Highest Method - Examine all VAMOSC values for the UICs on which the item was installed and select the highest value.

The only difference in all six methods was the manner in which the cost data was derived for the variable cost segment of the shortage cost. The Acquisition Price Method used the square root of an average cost of the item, and the remaining methods used VAMOSC data as a function of item essentiality. For all methods, the cost was priced out over the backorder period (LT*) to obtain the variable cost. The variable cost was then summed with the fixed cost to determine the shortage cost for an item.

All methods included the capability to use a percentage of the computed shortage costs to comply with budget or Supply Material Availability (SMA) constraints. This capability was used in the study in two ways. A percentage of the computed λE was selected to yield an 85% SMA and a percentage of the computed λE was selected so that inventory investment would equal today's investment. The percentage was multiplied by every item's computed λE. Therefore, every item retains a unique λE value whose relative importance does not change. That is, if Item A is 10 times more important than Item B as reflected in their calculated λE values and each λE value is reduced by 15%, Item A's λE value will still be 10 times larger than Item B's λE value.

C. EXAMPLES. Hypothetical item data found in TABLE II will be used to illustrate the six methods of calculating the variable cost.

TABLE II

Hypothetical Item Data

Data Name with DEN in parenthesis	Value
Replacement Price (B055)	$ 9,000.00
Repair Price (B055A)	$ 1,000.00
Regenerations (B074A)	1.0
Quarterly Demand (B074)	2.0
Procurement Leadtime (B011A)	480 days
Repair TAT (B012F)	120 days
VAMOSC Cost Data	
UIC 1 Cost	$10,000,000
UIC 2 Cost	$14,000,000
UIC 3 Cost	$18,000,000
Population Data	
UIC 1 Pop	6 (4+2)
APPL 1 Pop	4
APPL 2 Pop	2
UIC 2 Pop	3 (1+1+1)
APPL 3 Pop	1
APPL 4 Pop	1
APPL 5 Pop	1
UIC 3 Pop	1

Using the data in TABLE II, C* and LT* can be calculated.

$$C^* = \left(1 - \frac{B074A}{B074}\right) B055 + \left(\frac{B074A}{B074}\right) B055A = (1/2)\ 9000 + (1/2)\ 1000 = \$5{,}000.00$$

$$LT^* = \left(1 - \frac{B074A}{B074}\right) B011A + \left(\frac{B074A}{B074}\right) B012F = (1/2)\ 480 + (1/2)\ 120 = 300 \text{ days}$$

Fixed Cost

Fixed Cost = Administrative Cost to Order + Administrative Cost to Backorder + Cost to Spot Buy

Administrative Cost to Order = \$570.00 (see page 4)

Administrative Cost to Backorder = Average Cost to Review an Item per Month x Procurement Leadtime in months

= (\$.26) x (16)

= \$4.16

For items with Item Essentiality of 1, 2 or 3

Cost to Spot Buy = 0

For items with Item Essentiality of 4

Cost to Spot Buy = (.33) (\$9000) = \$3000

Therefore, for items with Item Essentiality of 1, 2 or 3

Fixed Cost = \$570.00 + \$4.16 + 0 = \$574.16

For items with Item Essentiality of 4

Fixed Cost = \$570.00 + \$4.16 + \$3000 = \$3,574.16

1. Acquisition Price Method. The Acquisition Price Method calculates the variable cost by multiplying the square root of C* by LT*.

$$\text{Variable Cost} = \sqrt{5000}\ (300) = \$21{,}213.20$$

Adding the fixed cost and variable cost yields λE. TABLE III displays the values of the fixed cost, variable cost and λE using the Acquisition Price Method.

TABLE III

λE for the Acquisition Price Method

For Item Essentiality	The Fixed Cost Is:	The Variable Cost Is:	λE:
4	$3,574.16	$21,213.20	$24,787.36
3	$ 574.16	$21,213.20	$21,787.36
2	$ 574.16	$21,213.20	$21,787.36
1	$ 574.16	$21,213.20	$21,787.36

2. Lowest Method. The minimum UIC cost for the three UICs the hypothetical item appears on is $10M. The variable cost is calculated by dividing the $10M by 365, multiplying this value by LT* and an appropriate percentage parameter (see TABLE I).

For items with Item Essentiality of 2:

$$\text{Variable Cost} = \left(\frac{\$10M}{365}\right)(300)(.1) = \$821,917.81$$

For items with Item Essentiality of 3:

$$\text{Variable Cost} = \left(\frac{\$10M}{365}\right)(300)(.5) = \$4,109,589.04$$

For items with Item Essentiality of 4:

$$\text{Variable Cost} = \left(\frac{\$10M}{365}\right)(300)(1.0) = \$8,219,178.08$$

TABLE IV displays the values of the fixed cost, variable cost and λE using the Lowest Method. The Acquisition Price Method is used for items with Item Essentiality 1.

TABLE IV

λE using the Lowest Method

For Item Essentiality	The Fixed Cost Is:	The Variable Cost Is:	λE:
4	$3,574.16	$8,219,178.08	$8,222,752.24
3	$ 574.16	$4,109,589.04	$4,110,163.20
2	$ 574.16	$ 821,917.81	$ 822,491.97
1	$ 574.16	$ 21,213.20	$ 21,787.36

3. Average Method. Since the hypothetical item appears on three UICs, the average cost per UIC is calculated by summing the three UIC VAMOSC costs and dividing by three.

$$\text{Average Cost per UIC} = \frac{\$10M+\$14M+\$18M}{3} = \$14M$$

The Average Cost per UIC per day is calculated by dividing the Average Cost per UIC by 365 days. This value is then multiplied by LT* and the appropriate percentage parameter (dependent upon Item Essentiality value) yielding the variable cost.

For items with Item Essentiality of 2:

$$\text{Variable Cost} = \left(\frac{\$14M}{365}\right)(300)(.1) = \$1,150,684.93$$

For items with Item Essentiality of 3:

$$\text{Variable Cost} = \left(\frac{\$14M}{365}\right)(300)(.5) = \$5,753,424.66$$

For items with Item Essentiality of 4:

$$\text{Variable Cost} = \left(\frac{\$14M}{365}\right)(300)(1.0) = \$11,506,849.32$$

TABLE V displays the values of the fixed cost, variable cost and the λE using the Average Method. The Acquisition Price Method is used for items with Item Essentiality 1.

TABLE V

λE using the Average Method

For Item Essentiality	The Fixed Cost Is:	The Variable Cost Is:	λE:
4	$3,574.16	$11,506,849.32	$11,510,423.48
3	$ 574.16	$5,753,424.66	$5,753,998.82
2	$ 574.16	$1,150,684.93	$1,151,259.09
1	$ 574.16	$ 21,213.20	$ 21,787.36

4. Weighted Average Method. Each of the three UIC costs are multiplied by the UIC population. These three values are summed and then divided by the sum of the three UIC populations to get a weighted average cost per UIC.

$$\text{Weighted Average Cost per UIC} = \frac{(\$10M)(6)+(\$14M)(3)+(\$18M)(1)}{10} = \$12M$$

As in the Average Method, the Weighted Average Cost per UIC is divided by 365 and then multiplied by LT* and the appropriate percentage parameter yielding the variable cost.

For items with Item Essentiality 2:

$$\text{Variable Cost} = (\frac{\$12M}{365})(300)(.1) = \$986,301.37$$

For items with Item Essentiality 3:

$$\text{Variable Cost} = (\frac{\$12M}{365})(300)(.5) = \$4,931,506.85$$

For items with Item Essentiality 4:

$$\text{Variable Cost} = (\frac{\$12M}{365})(300)(1.0) = \$9,863,013.70$$

TABLE VI displays the values of the fixed cost, variable cost and λE using the Weighted Average Method. The Acquisition Price Method is used for items with Item Essentiality 1.

TABLE VI

λE using the Weighted Average Method

For Item Essentiality	The Fixed Cost Is:	The Variable Cost Is:	λE:
4	$3,574.16	$9,863,013.70	$9,866,587.86
3	$ 574.16	$4,931,506.85	$4,932,081.01
2	$ 574.16	$ 986,301.37	$ 986,875.53
1	$ 574.16	$ 21,213.20	$ 21,787.36

5. Mode Method. Since UIC 2 has the most applications, the Mode Cost equals $14M which equals the average cost per UIC calculated using the Average Method. Therefore, for this hypothetical item, the variable cost and λE calculations using the Mode Method are exactly the same as those using the Average Method (TABLE V).

6. Highest Method. The maximum UIC cost for the three UICs the hypothetical items appears on is $18M. The variable cost is calculated by dividing the $18M by 365, multiplying this value by LT* and an appropriate percentage parameter.

For items with Item Essentiality 2:

$$\text{Variable Cost} = \left(\frac{\$18M}{365}\right)(300)(.1) = \$1,479,452.06$$

For items with Item Essentiality 3:

$$\text{Variable Cost} = \left(\frac{\$18M}{365}\right)(300)(.5) = \$7,397,260.27$$

For items with Item Essentiality 4:

$$\text{Variable Cost} = \left(\frac{\$18M}{365}\right)(300)(1.0) = \$14,794,520.54$$

TABLE VII displays the values of the fixed cost, variable cost and λE using the Highest Method. The Acquisition Price Method is used for items with Item Essentiality 1.

TABLE VII

λE using the Highest Method

For Item Essentiality	The Fixed Cost Is:	The Variable Cost Is:	λE:
4	$3,574.16	$14,794,520.54	$14,798,094.70
3	$ 574.16	$ 7,397,260.27	$ 7,397,834.43
2	$ 574.16	$ 1,479,452.06	$ 1,480,026.22
1	$ 574.16	$ 21,213.20	$ 21,787.36

D. INPUT DATA. Data elements which were necessary to conduct the study; e.g., Equipment Identification Code (EIC), population and Military Essentiality Code (MEC), were obtained from the Master Data File (MDF) and Levels 17 and 25 of the Weapons System File (WSF). A detailed description of the input development procedure is contained in Appendix C. Separate input records were developed for each unique application of an item. Since IMECs were assigned to every application of an item, more than one IMEC value could be assigned to an item. Item essentiality was included in the study based on the concept of IMECs. Since there is no approved technique of determining essentiality for items with more than one IMEC value, this analysis used only items with one IMEC value. This occurs when the item has only one application or every application of the item is assigned the same IMEC value. Therefore, the essentiality of the item is the unique value of the IMEC assigned to the item. Since IMECs were only available for SPCC and not Navy Aviation Supply Office (ASO) at the start of the analysis, the study was conducted only for SPCC. Based on the above criteria, 1,095 active 7H Cog items were selected for the analysis. In general, an item is considered active if any of the current demand, repair or leadtime observations are greater than zero. (The active item criteria are listed in Appendix D.)

The input items are distributed by MARK and item essentiality in TABLE VIII. MARK is determined by demand and cost of an item. MARK 0 items have demand forecasts less than .25 per quarter. MARK III and IV items are high cost items with MARK III representing medium demand (.25 to 5 per quarter) and MARK IV representing high demand (greater than 5 per quarter). Compared to reference (10) of Appendix A, this analysis includes a higher percentage of items with essentiality of 4 and a lower percentage of items with essentiality of 2 than the desired distribution for 7H items. Reference (10) of Appendix A, states that 5% of the items should have essentiality of 4 compared to 12% found in this study. The costs (standard price (DEN B053)) of the input items are also segmented by item essentiality in TABLE VIII. In general, for the items in this analysis, the higher priority items are also more expensive.

TABLE VIII
Distribution by Item Essentiality and MARK

	Item Essentiality					
	1	2	3	4	Total	%
MARK 0 MARK III MARK IV	231 35 0	185 66 1	301 134 9	106 27 0	823 262 10	75 24 1
TOTAL	266	252	444	133	1,095	
%	24	23	41	12		
Average Cost Per Item ($)	7,000	6,000	11,000	15,000		

VAMOSC data which was required to complete this analysis was obtained from reference (11) of Appendix A. VAMOSC data contains the operating and support costs of individual Navy ships for a fiscal year. (Fiscal year 1981 was used in the study.) Only active ships in commission for the entire fiscal year are reported in the VAMOSC data. Ships newly commissioned or decommissioned during the fiscal year are not included. The total operating and support cost for a ship is determined by summing across five major categories of costs: direct unit costs, direct intermediate maintenance costs, direct depot maintenance costs, direct recurring investment costs and indirect operating and support costs. A complete description of these costs is provided in reference (12) of Appendix A.

E. EVALUATION CRITERIA. The results contain statistics pertaining to the shortage costs (λE) calculated by each of the six methods evaluated. The statistics include averages, standard deviations, maximum and minimum values, and are displayed separately for each item essentiality value. The shortage costs SPCC currently use are noted in the results for comparison reasons. The risks calculated from the shortage costs are shown in the same format as the shortage costs.

The Computation and Research Evaluation System (CARES) analyzer was used in comparing the six proposed methods of computing shortage cost with the current method. The CARES analyzer which is described in reference (13) of Appendix A is an analytic inventory model that computes investment and performance statistics. (The integrated repair model option was applied in this analysis.) The output was analyzed using 100% of the computed shortage costs for each method. The capability of taking a percentage of the shortage costs was used to obtain similar SMA and similar requirements for each method in two additional series of output statistics. The output statistics generated by CARES which were pertinent to this analysis are listed and discussed below.

TABLE IX

Time-Weighted, Essentiality-Weighted Shortage Cost Segmented by Item Essentiality
(Dollars)

Essentiality/ Statistics		Acquisition Price	Lowest	Average	Wt. Avg.	Mode	Highest
Item Essen-tiality 1 266 Items	AVG	21,198	21,198	21,198	21,198	21,198	21,198
	SD	28,595	28,595	28,595	28,595	28,595	28,595
	MIN	678	678	678	678	678	678
	MAX	251,208	251,208	251,208	251,208	251,208	251,208
Item Essen-tiality 2 252 Items	AVG	19,779	3,605,504	4,262,907	4,298,480	5,077,578	5,201,753
	SD	24,038	4,503,681	4,486,107	4,488,162	4,875,641	4,837,389
	MIN	1,072	150,368	268,630	268,630	269,510	269,509
	MAX	119,199	21,995,608	22,705,005	22,705,005	23,414,403	23,414,403
Item Essen-tiality 3 444 items	AVG	22,667	12,169,051	14,324,563	14,342,132	18,128,988	18,825,456
	SD	46,762	16,873,727	16,900,099	16,939,216	18,258,673	18,451,893
	MIN	1,116	488,152	626,400	626,400	626,400	626,400
	MAX	611,286	98,812,337	99,530,648	99,530,648	102,497,474	102,497,475
Item Essen-tiality 4 133 Items	AVG	38,291	12,628,126	18,601,286	18,622,736	30,982,559	31,648,149
	SD	77,919	16,645,885	15,749,819	15,753,796	27,352,132	27,326,594
	MIN	3,055	1,514,006	1,895,786	1,895,786	1,895,786	1,895,786
	MAX	865,281	126,225,792	126,225,792	126,225,792	165,192,672	165,192,672

NOTE: Current SPCC shortage cost (λE) for 7H material range from \$.015 to \$1250.

B. RISKS. TABLE X displays the average, standard deviation, minimum and maximum values for the risk calculation segmented by Item Essentiality for each of the six methods of calculating the variable cost. Since the value of the risk is used directly to calculate the reorder level, the risk calculation has a more direct affect on the overall inventory model than the shortage cost calculation.

The Average and Weighted Average Methods of calculating the variable cost produce risks which are very close in value, as are the Highest and Mode Methods. Risks were not computed for items with either zero demand forecasts or zero requisition forecasts. Therefore, 364 items were excluded from TABLE X.

TABLE X

Risk Segmented by Item Essentiality

Essentiality	Statistics	Acquisition Price	Lowest	Average	Wt. Avg.	Mode	Highest
Item Essentiality 1	AVG	.0642	.0642	.0642	.0642	.0642	.0642
	SD	.1262	.1262	.1262	.1262	.1262	.1262
124 Items	MIN	.0003	.0003	.0003	.0003	.0003	.0003
	MAX	.8820	.8820	.8820	.8820	.8820	.8820
Item Essentiality 2	AVG	.0512	.0010	.0008	.0008	.0006	.0006
	SD	.0708	.0018	.0014	.0014	.0012	.0012
170 Items	MIN	.0040	.0000	.0000	.0000	.0000	.0000
	MAX	.5173	.0145	.0091	.0086	.0074	.0074
Item Essentiality 3	AVG	.0545	.0005	.0004	.0004	.0003	.0003
	SD	.0626	.0018	.0010	.0011	.0008	.0008
348 Items	MIN	.0027	.0000	.0000	.0000	.0000	.0000
	MAX	.3296	.0191	.0108	.0108	.0108	.0108
Item Essentiality 4	AVG	.0524	.0004	.0003	.0003	.0002	.0002
	SD	.0614	.0009	.0005	.0005	.0003	.0003
89 Items	MIN	.0106	.0000	.0000	.0000	.0000	.0000
	MAX	.3195	.0065	.0034	.0034	.0018	.0016

C. CARES OUTPUT. The impact that time-weighted, essentiality-weighted shortage costs have on cost and material availability is evaluated under three scenarios. First, the λE computed as described previously is discussed. Second, the computed λE is multiplied by a factor to reduce the λE used in the risk formula. The factor was selected so that the resulting SMA equals the Naval Supply Systems Command (NAVSUPSYSCOM) goal of 85% (reference (14) of Appendix A). Third, the computed λE is multiplied by a different factor so that the resulting inventory investment equals today's budget. The CARES output statistics for the Acquisition Price, Lowest, Average and Highest Methods are displayed in the TABLEs XI, XII and XIII. (CARES processed 956 of the 1,095 input items shown in TABLE VIII because newly provisioned items were excluded.) As expected, the Weighted Average and Mode methods generated nearly identical results as the Average and Highest methods, respectively. Therefore, the Weighted Average and Mode methods were excluded from the tables to avoid repetition and simplify meaningful comparisons. The Base Case represents the current method of determining shortage costs in which the same value is assigned to an entire Cog of items. The specific value is dependent on the available funding for the Cog.

1. Computed Shortage Costs. TABLE XI shows the results for all 956 input items in which 100% of the shortage cost (λE) was used in each of the proposed methods. Results are shown for two Base Cases: one with the target goal of 85% SMA and the other when the goal is 97% SMA which coincides with the SMA of the VAMOSC based methods. Of the methods evaluated, the Lowest, Average and Highest produced nearly identical results because all three methods computed similar risks. The Acquisition Price Method offered the least protection

(highest risk) and hence, lowest inventory costs of the proposed methods because the item's average acquisition price is much smaller than the VAMOSC data. The proposed methods require 20 times more safety level and more than twice as much inventory investment to increase SMA by 12 percentage points and improve ADD by 47 days when compared to the Base Case at 85% SMA. When the λE value was increased to $500,000 in the Base Case to obtain an SMA comparable to the Lowest, Average and Highest Methods, the safety level, requirements and ADD figures were less in the Base Case. More specifically, to obtain approximately a 97.5% SMA with the proposed and base case methods, the proposed methods require 10% more safety level investment ($20.7M compared to $18.9M), 6.5% more requirements investment ($59.9M compared to $56.2M) and produce a 13% longer ADD (11.9 compared to 10.5). The Base Case Method (λE = $500K) appears to produce the most favorable results in TABLE XI.

Since five of the six proposed methods are based on essentiality, the results were segmented by item essentiality and also displayed in TABLE XI. The proposed methods which include essentiality; i.e., Lowest, Average and Highest but not Acquisition Price, have a lower SMA for items with essentiality of 1 (91% versus 95%) than the Base Case Method with a similar SMA of 97.6% for all items. The proposed methods were able to support the higher priority items better than the Base Case Method. By observing the SMA for items with essentiality of 3 and 4 the additional support by the proposed methods is not evident because the λE values were so large that the SMA for items with essentiality of 2, 3 and 4 were very similar. However, the ADD were more sensitive and show that the proposed methods provide better support for items with essentiality of 3 and 4 because the ADD was less for the proposed methods than the ADD of the Base Case method. The difference in performance is more obvious for items with essentiality of 1 because the smaller average acquisition price data is used in computing shortage costs instead of the larger VAMOSC data.

Since the target goal for SMA is 85% and the support of items by essentiality was not evident due to the large λE figures, additional CARES analyzer results were generated using smaller λE values to attain the 85% SMA goal. These results, which illustrate the support of items according to item essentiality, are discussed next.

TABLE XI

100% Shortage Cost

Items	Method	$ Net Safety Level(M) (Pos-Neg)C*	$ Requirements(M) (RL+Q)B053	SMA	ADD
Total 956 Items	Acquisition Price	9.3	40.0	94.2	22.1
	Lowest	20.6	59.9	97.4	11.9
	Average	20.7	59.9	97.4	11.9
	Highest	20.7	59.9	97.4	11.9
	Base Case (λE=$4K)	1.0	26.4	85.2	58.8
	Base Case (λE=$500K)	18.9	56.2	97.6	10.5
Item Essentiality 1 205 Items	Acquisition Price	1.1	5.4	90.7	45.2
	Lowest	1.1	5.4	90.7	45.2
	Average	1.1	5.4	90.7	45.2
	Highest	1.1	5.4	90.7	45.2
	Base Case (λE=$4K)	-.2	3.6	77.4	97.4
	Base Case (λE=$500K)	2.8	7.8	95.0	22.8
Item Essentiality 2 208 Items	Acquisition Price	2.9	8.3	95.8	19.5
	Lowest	6.4	12.7	98.5	9.0
	Average	6.5	12.7	98.5	9.0
	Highest	6.5	12.7	98.5	9.0
	Base Case (λE=$4K)	.2	4.9	86.9	54.9
	Base Case (λE=$500K)	5.7	11.8	98.5	9.4
Item Essentiality 3 424 Items	Acquisition Price	4.1	22.6	94.1	19.6
	Lowest	9.8	35.8	97.9	8.0
	Average	9.8	35.8	97.9	8.0
	Highest	9.8	35.8	97.9	8.0
	Base Case (λE=$4K)	.9	15.5	85.5	52.5
	Base Case (λE=$500K)	8.0	31.6	97.8	8.4
Item Essentiality 4 119 Items	Acquisition Price	1.2	3.7	94.1	27.3
	Lowest	3.3	6.0	96.2	18.0
	Average	3.3	6.0	96.2	18.0
	Highest	3.3	6.0	96.2	18.0
	Base Case (λE=$4K)	.1	2.4	84.3	69.3
	Base Case (λE=$500K)	2.4	5.0	96.0	18.9

2. <u>Reduced Shortage Costs Which Yield 85% SMA</u>. TABLE XII is similar to TABLE XI with the exception that the shortage cost values in the proposed methods were reduced to obtain 85% SMA. This reduction in shortage cost values produced a much greater variation in the evaluation statistics. The Base Case Method is also shown at 85% SMA for comparison. Shortage costs and risks required to obtain 85% SMA for each method are shown in Appendix E in the same format as TABLEs IX and X.

TABLE XII, which contains the results for all 956 items, shows that for the same SMA the proposed methods require three to four times as much safety level investment ($3.5M compared to $1.0M) and 20% more requirements investment ($31M compared to $26M), while reducing ADD by 10% (51 compared to 58) . Analyzing the results by item essentiality reveals that the proposed methods which include essentiality; i.e., Lowest, Average and Highest but not Acquisition Price, produce higher SMA and considerably shorter ADD for items with essentiality of 3 and 4 than the Base Case Method. More specifically, the Average method increases SMA for items with essentiality of 3 and 4 from 85% to 90% and reduces ADD by 24 days (from 53 to 29) for items with essentiality of 3 and by 30 days (from 69 to 39) for items with essentiality of 4 when compared to the Base Case results. To provide better support for higher priority items, the proposed methods which include essentiality allocate less support for lower priority items. The items with essentiality of 1 attain one-half as much SMA (38% compared to 77%) and two and one-half times longer ADD (240 compared to 97) than the Base Case.

Weighted performance statistics were computed for the Base Case and Average Methods for comparison reasons. Each requisition was weighted by the Item Essentiality associated with it. That is, requisitions with Item

Essentiality 1 were weighted by 1, Item Essentiality 2 by 2, Item Essentiality 3 by 3 and Item Essentiality 4 by 4. Therefore, the more essential requisitions were weighted heavier in computing overall SMA and ADD statistics for the Base Case and Average Methods. Under this performance criteria, the Average Method improves SMA from 85% to 88% and decreases ADD from 56 to 39 days when compared to the Base Case.

TABLE XII

85% SMA

Items	Method	\$ Net Safety Level(M) (Pos-Neg)C*	\$ Requirements(M) (RL+Q)B053	SMA	ADD
Total 956 Items	Acquisition Price	3.6	30.5	84.9	48.0
	Lowest	3.3	30.5	84.8	53.2
	Average	3.5	31.3	85.1	50.6
	Highest	4.0	32.4	85.1	49.7
	Base Case (λE=\$4K)	1.0	26.4	85.2	57.8
Item Essen-tiality 1	Acquisition Price	.1	4.0	82.6	82.3
	Lowest	-.8	2.9	37.7	239.8
	Average	-.8	2.9	37.7	239.8
	Highest	-.8	2.9	37.7	239.8
205 Items	Base Case (λE=\$4K)	-.2	3.6	77.4	97.4
Item Essen-tiality 2	Acquisition Price	1.2	6.2	88.9	42.6
	Lowest	1.2	6.1	84.0	47.5
	Average	.9	5.8	86.4	48.3
	Highest	.8	5.7	86.3	48.7
208 Items	Base Case (λE=\$4K)	.2	4.9	86.9	54.9
Item Essen-tiality 3	Acquisition Price	1.8	17.5	83.0	45.9
	Lowest	2.3	18.5	90.5	33.4
	Average	2.8	19.6	89.9	28.6
	Highest	3.3	20.8	89.9	26.5
424 Items	Base Case (λE=\$4K)	.9	15.5	85.5	52.5
Item Essen-tiality 4	Acquisition Price	.5	2.8	89.1	46.6
	Lowest	.6	3.0	91.3	36.5
	Average	.6	3.0	91.5	38.7
	Highest	.7	3.0	91.2	41.5
119 Items	Base Case (λE=\$4K)	.1	2.4	84.3	69.3

Each of the proposed methods necessitates greater safety levels and requirements to obtain the same SMA as the Base Case. The Acquisition Price Method requires a greater investment because this method offers better protection for the higher cost items. The remaining proposed methods which include essentiality require greater investments because the items with essentiality of 3 and 4 are more expensive than items with essentiality of 1 and 2 as shown in TABLE VIII. Therefore, the methods which include essentiality also stock more high cost items.

Comparing the Highest Method with the Base Case reveals that increasing and decreasing safety level by the same amount, produces more of a negative impact on SMA than a positive impact. Specifically, the results for items with essentiality of 1 in TABLE XII show that decreasing safety level from the Base Case to the Highest method by $.6 million, decreases SMA by 39.7 percentage points and extends ADD by 142.4 days. For items with essentiality of 2 in TABLE XII, increasing safety level from the Base Case to the Highest method by $.6 million, results in a similar SMA and reduces ADD by just 6.2 days. The results for items with essentiality of 3 and 4 are similar to the results of items with essentiality of 2. A considerable increase in safety level produces a slight improvement in performance; i.e., SMA and ADD, as compared to the decline in performance when decreasing safety level by the same amount for items with essentiality of 1.

As previously stated, the input data for this analysis contained 12% items with essentiality of 4, whereas the 7H universe is expected to have only 5% of its items coded with an essentiality of 4. Since items with essentiality of 4 are more expensive than other items in this sample, the investments of the proposed methods which involve essentiality and offer the best support for items with essentiality of 4, are probably overstated due to the inclusion of a higher percentage of these more expensive items in the sample of input than the 7H universe.

3. Reduced Shortage Costs Which Yield the Current Requirements Budget. The results presented to this point compared the safety level, requirements and ADD among the various methods while maintaining a similar SMA. The following results displayed in TABLE XIII are based on equal investments and compare SMA and ADD.

Since SPCC currently executes at 72% SMA for 7H material, the shortage cost was adjusted in the Base Case method to obtain 72% SMA. The requirements necessary to obtain 72% SMA for the sample of input items in this analysis was $21.4 million. The shortage cost values were adjusted in the Acquisition Price and Average Methods to obtain as close to $21.4 million of requirements as possible. Shortage costs and risks required to allocate $21.4 million in requirements for each method are shown in Appendix F in the same format as TABLEs IX and X. The Lowest and Highest Methods were excluded from these results because of their similarity to the Average Method.

Observing the results for all 956 items shows that by using similar safety level and requirements, the Base Case SMA is 15.1 and 10.2 percentage points higher and the Base Case ADD is 21.8 and 6.5 days less when compared to the Acquisition Price and Average Methods, respectively. The results segmented by item essentiality reveal the Average Method provides better support for higher priority items, whereas the Acquisition Price and Base Case Methods offered better support for items with essentiality of 2 than other items. The Average Method has 23.3 percentage points lower SMA and 89.1 days longer ADD than the

Base Case Method for items with essentiality of 1. Although the Average Method has an overall lower SMA and longer ADD than the Base Case Method, it generates a higher SMA (by 5.5 percentage points) and a shorter ADD (by 25.6 days or 23% shorter) than the Base Case for items with an essentiality of 4. Based on equal investments, the Acquisition Price Method offers the poorest results because this method provides support based on the cost of the item, with the most expensive items (disregarding essentiality) receiving the most protection. The Average Method shows poorer overall results than the Base Case because the Average Method provides support based on essentiality. Since the higher priority items are more expensive (in this sample) and SMA is costly to increase for these items, most of the investment (69% of the investment) is used for items with essentiality of 3 and 4.

TABLE XIII

Equal Requirements ($21.4M)

Items	Method	$Safety Level(M)	$Requirements(M)	SMA	ADD
Total 956 Items	Acq. Price	-1.7	21.6	57.0	125.9
	Average	-1.7	21.5	61.9	110.6
	Base Case	-1.9	21.4	72.1	104.1
Item Essentiality 1 205 Items	Acq. Price	-.6	3.2	55.1	154.0
	Average	-.7	3.0	37.7	239.8
	Base Case	-.6	3.3	61.0	150.7
Item Essentiality 2 208 Items	Acq. Price	-.5	4.1	68.8	112.1
	Average	-.7	3.7	64.2	133.3
	Base Case	-.6	3.9	78.5	90.4
Item Essentiality 3 424 Items	Acq. Price	-.5	12.1	51.1	129.4
	Average	-.3	12.5	62.1	104.3
	Base Case	-.5	12.1	70.8	103.0
Item Essentiality 4 119 Items	Acq. Price	-.1	2.2	67.3	115.9
	Average	0	2.3	77.5	86.1
	Base Case	-.2	2.1	72.0	111.7

IV. SUMMARY

The Navy does not currently measure the cost of a shortage. The UICP levels calculation assigns the same shortage cost value to an entire Cog of items. The specific value is determined to maximize the percentage of requisitions satisfied given a predetermined investment constraint. Thus, the shortage cost is an implicit cost based on budget limitations. Each item within a Cog has the same shortage cost regardless of the item's military essentiality or any other item characteristics. This analysis evaluates procedures designed to measure the actual time-weighted, essentiality-weighted shortage cost (λE). One of the methods evaluated for computing shortage costs is based on the item's average acquisition price since the price is the minimum measure of how much the Navy is willing to spend to avoid a shortage. Shortage costs are also computed using the cost to operate and support a ship. This method is based on the assumption that the value of a ship's primary mission capabilities is equivalent to the amount of money the Navy is willing to spend to operate and support the ship. The five methods which considered the ship's operating and support costs used different percentages of these costs based on the essentiality of the item to the ship's primary mission. These five methods differed from each other in their treatment of the problem of which ship's operating and support costs should be used when an item is on more than one ship. While these five methods yielded similar results, the Average Method, which uses a simple average of the different ship's costs, is the best approach.

For the Average Method, the λE's averaged \$21K for Item Essentiality 1, \$4.3M for Item Essentiality 2, \$14.3M for Item Essentiality 3 and \$18.6M for Item Essentiality 4. More importantly, the corresponding acceptable risks of stockout were 6% for Item Essentiality 1 and less than 1% for all other items. The λE's SPCC currently use for this material range from \$.015 to \$1,250. Comparing these costs, one can see that the current ICP shortage costs are orders of magnitude too small.

The CARES analyzer was used to evaluate what impact the calculated λE values will have on performance (in terms of SMA and ADD) and cost (in terms of safety level and requirements) under three scenarios. First, the λE computed as described above was compared to the current method of a fixed shortage cost for all items. Using the Average Method of computing E increases the SMA 12 percentage points and decreases ADD 47 days for a 127% increase in inventory investment. Since the Average Method of computing λE yields 97.4% SMA, the second scenario selected a percentage of the computed λE which yielded 85% SMA, the goal for SMA. The percentage was multiplied by every item's computed λE. Therefore, every item retains a unique λE value whose relative importance does not change. That is, if Item A is 10 times more essential than Item B as reflected in their calculated λE values and each λE value is reduced by 15% to project 85% SMA, Item A's λE value will still be 10 times larger than Item B's λE value. Under the constant 85% SMA comparison, the Average Method of calculating λE increased inventory investment 18%. However, the increased investment provided better SMA and lower ADD for the more essential items as seen in TABLE XIV. The last two rows in TABLE XIV display the combined SMA and ADD statistics for all the items in the sample. The average statistics are computed in the normal manner where each requisition is weighted equally. The weighted average statistics weight each requisition by the Item Essentiality. Thus, the more important (essential) requisitions receive more weight in the computation of SMA and ADD. Under this performance criteria SMA improves from 85 to 88% and ADD decreases from 56 to 39 days (a 30% reduction). The weighted average statistics provide a better indication of how well the system is supporting essential items. Applying the 18% increase in inventory investment to the current budget for 7H Cog requirements (reorder level, order quantity and economic repair quantity) yields an additional investment of $194M (after offsetting the increased requirements by the expected available assets). Therefore, a 30% reduction in weighted ADD can be achieved at a cost of $194M.

TABLE XIV

	SMA (%)		ADD (Days)	
	Base Case	Avg. Method	Base Case	Avg. Method
Item Essentiality 1	77	38	97	240
Item Essentiality 2	87	86	55	48
Item Essentiality 3	86	90	53	29
Item Essentiality 4	84	92	69	39
Average	85	85	58	51
Weighted Average	85	88	56	39

The third scenario used a percentage of the λE so that inventory investment could be evaluated at the current funding level. Under this comparison the λE's are drastically reduced (by a factor of .9983) to a level which is comparable to the current ICP shortage costs. This evaluation technique shows the Average Method lowers the overall SMA by 10 percentage points and adds 6.5 days to ADD. However, the Average Method does reduce the ADD for Item Essentiality 4 items (from 112 to 86) and maintains the same ADD (103) for Item Essentiality 3 items while increasing ADD significantly for Item Essentiality 2 (43 days) and Item Essentiality 1 (89 days) items.

V. CONCLUSIONS

The Average Method for determining time-weighted, essentiality-weighted shortage costs (λE) for SPCC items should be implemented during resystemization. Implementation of this method will require a new DEN for λE, and a computer program to calculate and annually update the λE value for each NIIN.

The Average Method determines a unique λE value for each item equal to the sum of a fixed cost and a variable cost. The fixed cost portion equals the sum of the administrative cost to order, the administrative cost to backorder and, for high priority items (Item Essentiality 4), the cost of a spot buy. For items with the lowest essentiality value (Item Essentiality 1 items) the variable cost portion is determined by multiplying the square root of the average acquisition price (C*) by the average acquisition time (LT*). For items which are not of the lowest essentiality (Item Essentiality 2, 3 or 4 items) the Average Method determines the variable cost portion of λE by calculating the simple average of the yearly operating and support costs for each ship the item appears on. This yearly average is then converted into a quarterly average cost and multiplied by the average acquisition time (LT*) and a percentage parameter which varies by the Item Essentiality value of the item. The percentage parameter equals 10%, 50% and 100% for items with Item Essentiality values 2, 3 and 4, respectively.

Since implementation of the Average Method to calculate λE is a long range effort, SPCC should in the short term use the mean of the actual λE values calculated in this study using the Average Method in lieu of the budget constrained values used currently. The shortage cost values in UICP could then vary by essentiality since the mean calculated using the Average Method varies by essentiality. The shortage costs and risks associated with these calculations are displayed in Appendix E. The average λE values calculated using the Average Method to obtain 85% SMA are approximately \$30, \$6,000, \$20,000 and \$26,000 for items with Item Essentiality values 1, 2, 3 and 4, respectively. Using these values for λE in UICP would achieve a 30% reduction in weighted ADD at a cost of \$194M.

VI. FURTHER EFFORTS

The methods evaluated in this study assume that an item has a single IMEC value even when the item has multiple applications. Yet an item can appear on more than one equipment or more than one ship resulting in multiple applications per item. Reference (4) of Appendix A proposes to average the IMEC values of each application to determine a single essentiality value for the item. This study proposes to average the VAMOSC data for the ships the items appear on to determine a single ship's cost and to use the average IMEC value and the average ship's cost to determine the shortage cost value for the item. An alternative method of calculating λE for items with multiple applications, which should be evaluated, is to develop a shortage cost for each application of the item based on the application's IMEC value and VAMOSC data. The unique shortage cost for the item would then be determined by calculating a simple average of the application shortage costs. Therefore, instead of determining the shortage costs based on two averages (for the IMEC value and for the ship's cost) the shortage cost would be based on one average (across the application shortage costs).

Because the operating and support costs are not available for equipments, a percentage of the ships operating and support costs was used for those items which were neither most or least essential (items with essentiality of 2 or 3). Using equipment cost data to calculate λE for items with essentiality 2 or 3 should be evaluated if the data become available.

VII. RECOMMENDATIONS

A. LONG RANGE. FMSO recommends implementation of the Average Method to determine shortage costs for SPCC items.

B. SHORT RANGE. FMSO recommends that SPCC use the average E values found in Appendix E, which vary by essentiality, in UICP in place of the budget constrained shortage cost values used currently.

C. FURTHER EFFORTS. FMSO recommends follow-on analysis in the following areas:

1. Develop a shortage cost for each application of an item. Calculate the average of the application shortage costs instead of two averages (one for IMEC values and a second for ship operating costs).

2. Use equipment cost data to calculate the shortage cost for items with essentialities of 2 and 3 if such data become available.

APPENDIX A: REFERENCES

1. DODI 4140.39.

2. Supply Systems Design Specifications (SSDS) Application/Operation (A/O) D01 (Leadtime Computation, Demand Forecasting Activity Stocking Criteria and Levels Computation) of 1 Jan 1983.

3. FMSO ltr 9322-D93/JAM/150 5250 of 26 May 1982.

4. Operations Analysis Report 154.

5. G. Hadley and T. M. Whitin, Analysis of Inventory System, Prentice-Hall, Inc. 1963.

6. SPCC memo 799/EE/245 of 25 Aug 1982.

7. Telcon between Ms. Kim Hoff (FMSO 9322) and Mr. Bob Forbes (SPCC 034X) on 15 Jun 1982.

8. COMNAVSUPSYSCOM ltr 04A3/PRV of 27 Aug 1982.

9. SPCC ltr 340/WED/169 4400 of 6 Apr 1982.

10. CNO memo Ser 412E/3973834 of 28 Jul 1981.

11. COMNAVSEASYSCOM Code 01732V.

12. Visibility and Management of Operating and Support Cost - Ships, Volume 1, Report Description, June 1982.

13. SSDS A/O D56 (Computation and Research Evaluation System (CARES) III) of 19 Jul 1983.

14. NAVSUPINST 5220.15A.

APPENDIX B: BACKORDER PERIOD (LT*)STATISTICS

Backorder period statistics were computed as a weighted average of leadtime and TAT and are shown in the table below:

Backorder Period (LT*) Segmented by Item Essentiality (DAYS)

Item Essentiality 1 266 Items	AVG	386
	SD	167
	MIN	104
	MAX	912
Item Essentiality 2 252 Items	AVG	346
	SD	164
	MIN	45
	MAX	1,095
Item Essentiality 3 444 Items	AVG	308
	SD	165
	MIN	29
	MAX	912
Item Essentiality 4 133 Items	AVG	394
	SD	161
	MIN	118
	MAX	912

APPENDIX C: INPUT FILE DEVELOPMENT

The purpose of this appendix is to describe how the data elements needed to calculate λE for 7H Cognizance Symbol (Cog) active items were developed. A Computation and Research Evaluation System (CARES) input file of 7H active items provided the National Item Identification Numbers (NIINs) for this study. Level 17 of the Weapons System File (WSF), Level 25 of the WSF and the Master Data File (MDF) were used to develop the data. The MDF was used to develop the NIIN to Allowance Parts List (APL) relationships and Level 25 of the WSF developed the APL to UIC relationships. Level 25 of the WSF was also used to extract needed data elements from Level 17 of WSF. TABLE I indicates what data elements were extracted from each of these data files (the DEN for the data element is in parenthesis).

TABLE I
Data Elements Needed to Calculate the IMECs

Level 17 of the WSF	DENs
UIC - Unit Identification Code	(D008)
UIC AINAC - UIC Application/Identification Number Activity Code	(D029)
APL - Allowance Parts List	(D008)
APL AINAC	(D029)
RIN - Record Identification Number	(E221)
RIN POP - RIN Population	(D011)
EIC - Equipment Identification Code	(D008D)
MCC - Mission Criticality Code	(C003Y)
Level 25 of the WSF	
UIC	(D008)
UIC AINAC	(D029)
APL	(D008)
APL AINAC	(D029)
QTY PER APPL - Quantity per Application	(D011)
MDF	
NIIN - National Item Identification Number	(D046D)
COG - Cognizance	(C003)
FSC - Federal Supply Class	(C042)
APL	(D009)
APL AINAC	(D029)
NIIN to APL POP	(D011)
PART to COMP MEC - Part to Component Military Essentiality Code	(C008E)

The data elements from these three files were consolidated resulting in unique data records per NIIN/APL/Record Identification Number (RIN)/Unit Identification Code (UIC) combination. Ship Type and Hull Number (STHN) were extracted from the Visibility and Management of Support Costs (VAMOSC) file and added to the data record. The STHN and Equipment Identification Code (EIC) for each record were converted to a ship class and lead EIC, respectively.

Mission Criticality Codes (MCCs) were extracted from the MCC worktape based on the ship family and lead EIC and added to the data record. If a record already contained an MCC from Level 17 of the WSF, it was overridden by the MCC from the worktape since the MCC worktape contained more recent data. Records with incomplete EICs were coded "Z" in the MCC data field while records with complete EICs but no match with the MCC worktape were coded with an MCC "1". The RIN POP was summed across identical NIIN/APL/EIC/UIC records resulting in unique data records per NIIN/APL/EIC/UIC. An Item Military Essentiality Code (IMEC) was determined for each record based on the MCC and Military Essentiality Code (MEC) as shown in TABLE II.

TABLE II

IMEC Determination Based on the MCC and the MEC

MCC	MEC	IMEC
5 or E	1	4
4 or D	1	4
3 or C	1	3
2 or B	1	2
1 or A	1	1
Z	Any	Blank
Any of Above	3	1
Any of Above	5	4

APPENDIX D: ACTIVE ITEM CRITERIA

An item is designated as "active" if any one of the following criteria is met.

1. Any of the following Data Element Numbers (DENs) are > 0.

A004A	System Recurring Demand Frequency Observation
A005	Current System Recurring Maintenance Demand Observation
A005A	Current System Recurring Overhaul Demand Observation
A005B	Current System Carcass Return Observation
A005C	Current System Other Service Demand Observation
A006	Current System Nonrecurring Demand Observation

2. Any Issue Observation (A006C Current System Issue Observation) purpose code other than A or W > 0.

3. Item is MARK 2, 3, or 4 (B067B, C, D).

4. Numeric DRIPR Code for any one of DENs B001A, B, C, D, or E.

5. System Order Quantity (B021) = 0.

6. Any of the leadtime observations > 0.

B010G	Cumulative Production Leadtime Observation
B011G	Cumulative Procurement Leadtime Observation

7. Any of the Repairable DENs > 0.

F009D	Cumulative Repair Induction Quantity
B012G	Cumulative Navy Reporting Repair in Process Time Observation
B012K	Cumulative Navy Nonreporting and Commercial Repair TAT Observation

8. Item is in a family (C001A $\neq$ Blank).

9. System Internal Due-In, Purpose Code A and Condition Code A (A008B) > 0.

10. Item has Maintenance Demand Observation History Code (B052) other than a space.

APPENDIX E: SHORTAGE COSTS AND RISKS WHICH YIELD 85% SMA

TIME-WEIGHTED, ESSENTIALITY-WEIGHTED SHORTAGE COSTS (SEGMENTED BY ITEM ESSENTIALITY) USED TO OBTAIN 85% SMA

		Acquisition Price	Lowest	Average	Highest
Item	AVG	6,147.55	48.76	29.68	21.20
Essentiality 1	SD	8,292.65	65.72	40.03	28.60
124 Items	MIN	196.62	1.56	.95	.68
	MAX	72,850.32	577.78	351.69	251.21
Item	AVG	5,736.09	8,292.66	5,968.07	5,201.75
Essentiality 2	SD	6,971.11	10,358.47	6,280.55	4,837.39
170 Items	MIN	310.88	345.85	376.08	269.51
	MAX	34,567.71	50,589.90	31,787.01	23,414.40
Item	AVG	6,573.64	27,988.82	20,054.40	18,825.46
Essentiality 3	SD	13,561.20	38,809.57	23,660.14	18,451.89
348 Items	MIN	323.64	1,122.75	876.96	626.40
	MAX	177,272.94	227,268.38	139,342.91	102,497.48
Item	AVG	11,104.53	29,044.69	26,041,80	31,648.15
Essentiality 4	SD	22,596.67	38,285.54	22,049.75	27,326.59
89 Items	MIN	885.95	3,482.21	2,654.10	1,895.79
	MAX	250,931.49	290,319.32	176,716.11	165,192.67
% of λE used to obtain 85% SMA		29.0%	0.23%	0.14%	0.10%

Risks Segmented by Item Essentiality

to Obtain 85% SMA

		Acquisition Price	Lowest	Average	Highest
Item Essentiality 1 124 Items	AVG	.1476	.8993	.9324	.9488
	SD	.1725	.1064	.0884	.0784
	MIN	.0009	.1055	.1624	.2135
	MAX	.9626	.9997	.9998	.9999
Item Essentiality 2 170 Items	AVG	.1361	.1773	.1902	.1926
	SD	.1376	.2126	.2249	.2330
	MIN	.0138	.0010	.0017	.0015
	MAX	.7871	.8647	.8675	.8821
Item Essentiality 3 348 Items	AVG	.1481	.0766	.0831	.0883
	SD	.1322	.1325	.1366	.1414
	MIN	.0094	.0003	.0005	.0006
	MAX	.6289	.8944	.8861	.9159
Item Essentiality 4 89 Items	AVG	.1432	.0896	.0902	.0885
	SD	.1265	.1401	.1390	.1332
	MIN	.0356	.0022	.0020	.0017
	MAX	.6142	.7405	.7115	.6103

APPENDIX F: SHORTAGE COSTS AND RISKS WHICH YIELD THE CURRENT REQUIREMENTS BUDGET

Time-Weighted, Essentiality-Weighted Shortage Cost Calculation
(Segmented by Item Essentiality) Used to Allocate $21.4 Million in Requirements

		Acquisition Price	Average
Item Essentiality 1 124 Items	AVG	1,059.92	3.49
	SD	1,429.77	4.72
	MIN	33.90	.11
	MAX	12,560.40	41.45
Item Essentiality 2 170 Items	AVG	989.98	703.38
	SD	1,201.90	740.21
	MIN	53.60	44.28
	MAX	5,959.95	3,746.33
Item Essentiality 3 348 Items	AVG	1,133.35	2,363.55
	SD	2,338.10	2,788.52
	MIN	55.80	103.36
	MAX	30,564.30	16,422.56
Item Essentiality 4 89 Items	AVG	1,914.57	3,069.21
	SD	3,895.98	2,598.72
	MIN	152.75	312.80
	MAX	43,264.05	20,827.26
% of λE Used to Allocate $21.4M in Requirements		5.0%	0.165%

Risks Segmented by Item Essentiality
Used To Allocate $21.4 Million in Requirements

		Acquisition Price	Average
Item Essentiality 1 124 Items	AVG	.4052	.9891
	SD	.2232	.0334
	MIN	.0054	.6300
	MAX	.9934	1.0000
Item Essentiality 2 170 Items	AVG	.3975	.4715
	SD	.2169	.3215
	MIN	.0751	.0160
	MAX	.9554	.9824
Item Essentiality 3 348 Items	AVG	.4305	.3036
	SD	.2049	.2932
	MIN	.0521	.0043
	MAX	.9077	.9851
Item Essentiality 4 89 Items	AVG	.4296	.3155
	SD	.1858	.2695
	MIN	.1762	.0185
	MAX	.9023	.9545

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13. ABSTRACT

Currently, the Navy uses shortage costs which are fixed over a large range of items and independent of the item's average acquisition price, average acquisition time and military essentiality. Today's shortage costs are imputed costs based on a given budgetary goal. This analysis evaluates procedures designed to measure the actual time-weighted, essentiality-weighted shortage costs (λE). One of the methods evaluated for computing shortage costs is based on the item's average acquisition price, since this is the minimum measure of how much the Navy is willing to spend to avoid a shortage. Shortage costs are also computed using the cost to operate and support a ship. This method is based on the assumption that the value of a ship's primary mission capabilities is equivalent to the amount of money the Navy is willing to spend to operate and support the ship. Under this method, shortage cost for an item was then determined as a percentage of the ship's operating and support costs based upon that item's essentiality to the ship's primary mission. This report analyzes the alternative techniques used to measure the λE, recommends a specific method and discusses issues related to the implementation of the recommendation.

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