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JOINT OPERATIONAL STOCKS INVENTORY PURCHASING PRIORITIZATION METHODOLOGY

by

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Joint Operational Stocks (JOS) are used as a "revolving" inventory of end-use items available for loans to United States Special Operations Forces. The JOS items are administered by the United States Special Operations Command (USSOCOM) in Tampa, FL. By using a revolving inventory, USSOCOM reduces the total quantities of items that need to be stocked However, current stocks are inadequate to meet demand, and current funding is inadequate to fully stock all inventory items. Currently USSOCOM has no methodology to prioritize purchase decisions to provide the best support to Special Operations Forces, per dollar spent. This thesis provides a methodology to allocate limited financial resources in procuring additional JOS units of inventory to provide the greatest increase in mission support benefit to special operations forces. The methodology is applied to the current JOS inventory system, providing a recommended prioritized sequence of inventory purchases. This thesis is limited to those items in the JOS inventory that currently do not have adequate quantities to meet the current demand, yet have sufficient demand history to provide adequate data for analysis. The methodology developed, however, is generic in nature and can be applied again in the future as more data becomes available.

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JOINT OPERATIONAL STOCKS INVENTORY PURCHASING PRIORITIZATION METHODOLOGY

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ABSTRACT

Joint Operational Stocks (JOS) are used as a "revolving" inventory of end-use items available for loans to United States Special Operations Forces. The JOS items are administered by the United States Special Operations Command (USSOCOM) in Tampa, FL. By using a revolving inventory, USSOCOM reduces the total quantities of items that need to be stocked. However, current stocks are inadequate to meet demand, and current funding is inadequate to fully stock all inventory items. Currently USSOCOM has no methodology to prioritize purchase decisions to provide the best support to Special Operations Forces, per dollar spent. This thesis provides a methodology to allocate limited financial resources in procuring additional JOS units of inventory to provide the greatest increase in mission support benefit to special operations forces. The methodology is applied to the current JOS inventory system, providing a recommended prioritized sequence of inventory purchases. This thesis is limited to those items in the JOS inventory that currently do not have adequate quantities to meet the current demand, yet have sufficient demand history to provide adequate data for analysis. The methodology developed, however, is generic in nature and can be applied again in the future as more data becomes available.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification and validation is at the risk of the user.

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LIST OF ACRONYMS

USSOCOM	United States Special Operations Command
SOF	Special Operations Forces
OPLANS	Operational Plans
CONPLANS	Contingency Plans
FUNCPLANS	Functional Plans
POL	Petroleum, Oil, and Lubricants
MFP	Major Force Program
JOS	Joint Operational Stocks
SF	Special Forces
DA	Direct Action
SR	Special Reconnaissance
FID	Foreign Internal Defense
UW	Unconventional Warfare
CT	Combating Terrorism
CP	Counter-proliferation
CA	Civil Affairs
PSYOP	Psychological Operations
IW/C2W	Information Warfare/Command and Control Warfare
CS	Coalition Support
CSAR	Combat Search and Rescue
CD	Counter-drug Activities
CM	Counter-mine Activities
HA	Humanitarian Assistance
NGO	Non-Governmental Organizations
PVO	Private Volunteer Organizations
SA	Security Assistance
SL	Service Level
EBO	Expected Number of Backorders
AAM	Aircraft Availability Model
SESAME	Selected Essential-Item Stockage for Availability Method
ARROWS	Aviation Readiness Operation Weapon Systems
AVCAL	Aviation Coordinated Allowance List
NRFI	Not Ready For Issue
RFI	Ready For Issue
EFR	Expected Fill Rate
Ao	Operational Availability
PMISL	Percent Marginal Increase in Service Level
WPMISL	Weighted Percent Marginal Increasing Service Level
ALTEDS	Average Loan Time for Each Demand Satisfied
MNUDDALT	The Mean Number of Units Demanded During the Average Loan Time
SDNUDDALT	The Standard Deviation of the Number of Units Demanded During an Average Loan Time

SDDS	Standard Deviation of Demand Size
MDS	Mean Demand Size
CLT	Central Limit Theorem
CDF	Cumulative Distribution Function
UB	Upper Bound
SOC	Special Operations Command
SO	Special Operations

EXECUTIVE SUMMARY

Joint Operational Stocks (JOS) are a revolving inventory of end-use items that are available for loans to United States Special Forces personnel. The inventory is called "revolving" because items are issued to Special Operations Force (SOF) units for specific missions (operational and training), and returned to the JOS inventory after the missions are completed, then re-issued at the commencement of the next appropriate mission. The JOS items are administered by the United States Special Operations Command (USSOCOM) in Tampa, FL, but are physically located in Lexington KY. By using a revolving inventory, USSOCOM reduces the total quantities of items that need to be stocked. Current demand shows that the JOS inventory levels fall short in meeting Special Operations Forces (SOF) needs for certain items. USSOCOM recognizes that JOS inventories need to be increased, but has no methodology to identify how many units of each item are required, and in what order units should be purchased to provide the best support to SOF personnel. This thesis explores such a methodology. This thesis is limited to those items in the JOS inventory that currently do not have adequate quantities to meet the current demand, but have sufficient demand history to provide adequate data for analysis. The methodology developed, however, is generic in nature and can be applied again in the future as more data becomes available.

The method used is adapted from a marginal analysis technique used in one of the Navy's aviation inventory models. It prioritizes each additional unit of each end item by combining the percent marginal increase in service level with a mission usefulness factor per dollar cost. This combination results in a value which is assigned to a particular added unit of each end item. These values are then rank ordered from largest to smallest, resulting in a prioritized shopping list.

Essential to the computation of this value are the initial stock levels, the service levels for each added unit, the mission usefulness of each item, and the cost of each item. The initial stock levels and item cost are provided by USSOCOM. The initial service levels are computed based on the historical data as the ratio of the number of units issued to the total number of units requested. A computer program simulates the adding of one unit of inventory to the stock level of each end item. It determines the simulated service level by computing the number of units that would have been issued given the simulated stock level and the actual historical demand pattern, then dividing by the historical total number of units requested. The program continues the procedure of adding one more unit to the stock level and calculating the simulated service level until the number of added units reaches an upper bound.

The mission usefulness is derived from the results of a survey. The survey was disseminated throughout the Special Operations Forces community, with 57 responding. Respondents were asked to place each end item in one of six categories which are ordinally scaled from "never used" to "always used". Integer values of "0" through "5" are assigned, respectively, to each category. Results of all respondents are compiled in a frequency table for each end item. Frequencies are multiplied by the respective assigned integers and then summed for each item. After determining the largest of these resulting values, the mission usefulness values are "normalized" by dividing by the largest value and then multiplying by 100.

The results of this methodology provide USSOCOM with a feasible prioritized shopping list of items to purchase with a given budget. Through sensitivity analysis it appears that the main influence in the recommendation is the cost. For a given budget of $500,000, the resulting shopping list includes the maximum number of units the model can add of all items priced at under $1,000. There are, however, a combined 12 units of four end items valued at over $10,000 included in the list. The analysis also indicates that the mission usefulness factor has limited impact on the priority decision for the particular measure of added value used here.

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I. INTRODUCTION

> United States Special Operations Forces exist to support and defend the Constitution. They accomplish this through active participation in peacetime activities that dampen or deter conflict and, if these measures fail, by providing the National Command Authorities with forces capable of spearheading decisive victory as part of a joint team--anywhere in the world and under virtually any conditions.
>
> -U.S. Special Operations Command (USSOCOM) PUB 1

A. OVERVIEW OF SPECIAL OPERATIONS FORCES

Army, Navy, and Air Force Special Operations Forces (SOF) are considered to be the most highly trained and well-equipped forces in the world. Their small size, unique capabilities, and self-sufficiency make them rapidly deployable and highly effective, especially for small-scale, asymmetric contingencies. Special operations are conducted across the full spectrum of military operations, independently or in coordination with operations of conventional forces. In order for most theater-level campaigns to be successful, SOF units must be integrated into Operational Plans (OPLANS), Contingency Plans (CONPLANS), and Functional Plans (FUNCPLANS). The missions SOF units are assigned to perform are designed to complement conventional operations, not compete with them. (Joint Pub 3-05, 1998)

There are three major characteristics that distinguish SOF units from their conventional counterparts, which are listed below.

- Special operations require operator-level planning, detailed intelligence and knowledge of cultures and languages in the area where the mission is to be conducted. Rigorous training and rehearsals of the mission are integral to the conduct of the operation.

- Special operations are often conducted at great distances from operational bases employing sophisticated communication systems and the means of insertion, support and extraction to penetrate and return from hostile, denied, or politically sensitive areas.

- Special operations require discriminate and precise use of force. This may require development, acquisition and employment of weapons and equipment not standard for conventional forces. (Joint Pub 3-05, 1998)

1. Composition of Special Operations Forces

In the SOF community the units are primarily as follows:

- Army Special Forces
- Army Rangers
- Civil Affairs
- Psychological Operations
- Army Aviation
- Naval Special Warfare Units
- Navy SEALs
- Special Boat Units
- And Air Force Special Operations Elements

Some of these units perform one specific mission, while others can perform a variety of missions.

2. The primary and collateral missions performed by SOF

The following are primary and collateral missions performed by SOF units:

- Direct Action
- Special Reconnaissance
- Foreign Internal Defense
- Unconventional Warfare
- Combating Terrorism
- Counter-proliferation

- Civil Affairs
- Psychological Operations
- Information Warfare/Command and Control Warfare
- Coalition Support
- Combat Search and Rescue
- Counter-drug Activities
- Counter-mine Activities
- Humanitarian Assistance
- Security Assistance

B. LOGISTICS OVERVIEW

> Logistics provides the physical means for organized forces to exercise power. In military terms, it is the creation and sustained support of combat forces. Its objective is maximum sustained combat effectiveness.
>
> Rear Admiral Henry Eccles, USN, Ret.

In order to accurately define SOF logistics, it is important to look at the logistics process in general. The process is initiated by a specific type of unit that is assigned a mission, which creates requirements for supplies and services. Different units have unique requirements for each mission.

Each of the units performing one of the above missions will have certain requirements for supplies and services. A general list of supplies and services is listed below.

- Class I: Food and Water
- Class II: Clothing and Individual Equipment
- Class III: Petroleum, Oil, and Lubricants (POL)

- Class IV: Barrier and Construction Material
- Class V: Ammunition
- Class VI: Personal Demand Items
- Class VII: Major End Items
- Class VIII: Medical Supplies
- Class IX: Repair Parts
- Class X: Non-military Program Material

1. Support of Special Operations Forces

Under Title 10 of the U.S. Code, each service is required to provide logistical support to all of its forces, conventional and non-conventional. In general this applies to all 10 classes of supply listed above, and therefore means that USSOCOM has no direct responsibility for logistics support for SOF personnel, other than identifying requirements to the parent services of the Army, Navy, and Air Force.

Congress recognizes that USSOCOM has unique missions and capabilities that cut across traditional service mission boundaries. Therefore, they have unique requirements that are more appropriately funded separately from the parent services. Specifically, the Nunn-Cohen Amendment to the 1986 legislation establishes a separate major force program (MFP), MFP-11, which provides direct funding to USSOCOM to fund its own unique requirements. (USSOCOM PUB 1, 1996)

Of the 10 general classes of logistic requirements, the SOF forces have unique needs in only the class VII category of major end items. The parent services are responsible for the logistic needs of the other categories. To respond to the congressional mandate to provide support to SOF personnel for SOF unique items, USSOCOM developed an inventory of Joint Operational Stocks (JOS) consisting of major end items that are unique to SOF missions and personnel.

2. Joint Operational Stocks

The Joint Operational Stocks (JOS) are a joint, centrally managed inventory of USSOCOM reusable material. The inventory consists of special operations unique equipment which are technologically advanced and state-of-the-art. These items are issued to USSOCOM components for specific operations, and then returned upon completion of the operation. It is a revolving inventory system issued for specified loan periods. It is designed to enhance mission capability by providing specialized equipment, outside of parent service capabilities, to joint Special Operations Forces (SOF) for training and contingency operations worldwide.

USSOCOM is responsible for the purchase and maintenance of the inventory levels in the JOS. USSOCOM funds all maintenance, warranty tracking, storage, upgrade and replenishment of equipment.

As a rule of thumb, an item maintained in the JOS inventory should meet the following criteria:

- An item alleviates a documented or operational capability shortfall, or provides mission enhancements.
- An item provides enhanced, interim mission capability.
- An item reduces current SOF documented equipment deficiencies.
- An item is not a substitute for service authorized equipment shortages.
- An item is applicable to more than one component of the Special Forces (SF).
- An item is available for "off-the-shelf" procurement.

- An item is equipment that should have an expected utility/shelf-life of more than three years.
- An item is equipment which is employable in all regional areas of operations.
- An item does not require specialized storage or security.
- An item does not require permanent installation on unit equipment.
- An item requires minimal "train-up" to deploy/employ.
- An item is not required for permanent unit retention.

Some examples of JOS items include night vision goggles, sniper rifles, long-range thermal viewers, hand-held radios, protective vests, and personal water purification units. Currently, there are over 70 line items maintained in the JOS inventory. (USSOCOM Joint Operational Stocks Catalog, July 1998)

C. STATUS OF JOS

Current demand patterns show that the JOS inventory levels fall significantly short in meeting SOF needs for certain items. USSOCOM recognizes that JOS inventories need to be increased, but USSOCOM has no methodology to identify what to buy, how much to buy, and in what order to buy to provide the best support to Special Operations Forces.

During discussions with CAPT William Wright, USN, Mr. Phil Lamneck (GS-15), and CDR Francis Tisak, USN, of U.S. Special Operations Command (USSOCOM), Tampa FL, each expressed a need to establish a methodology for determining appropriate JOS inventory levels in order to provide justification for funding. Further, all three individuals expressed a desire to correlate inventory purchases to mission needs. It is believed that funding for JOS has been reduced due to a lack of a strong analytic argument as to what to buy, how much to buy, and in what order to buy. (Meeting at USSOCOM, November 1998) A point paper written by CDR Tisak is provided in Appendix A, which illustrates the need for USSOCOM to have continued JOS funding.

D. PURPOSE

This thesis provides a methodology to assist USSOCOM in answering two primary questions, how many units of each item are required, and in what order should units be purchased to provide the greatest support to Special Forces (SF) personnel for a given budget. In addition to determining the number of units of each item to be stocked in inventory, this thesis estimates relative mission usefulness values of current inventory items and makes recommendations regarding the allocation of limited funds to purchase additional current inventory items.

E. SCOPE

There are 71 end items in the JOS inventory. Of these, 23 have not experienced any demand and are not considered in this study. Of the other 48 items, 13 have always had enough inventory on hand to fill all demands. Hence, they are also excluded from the study. Of the remaining 35 end items, nine have only one year's worth of demand history, while the other 26 items have three years' worth of demand history.

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II. BACKGROUND

A. SPECIAL OPERATIONS FORCE (SOF)

1. History and Missions

The missions SOF units are required to perform are vastly different than those of conventional forces. SOF missions are conducted during peacetime as well as full-scale war, both independently and in conjunction with conventional forces. Congressional legislation and joint doctrine have led to the definition and development of specific SOF missions. These missions are grouped into two categories: Principal and Collateral.

2. Principal Missions

a. Direct Action (DA)

A direct action is defined as a short-duration strike and other small-scale offensive actions to seize, destroy, capture, recover or inflict damage on designated personnel or material in a denied area. When conducting a DA against strategic or operational targets, SOF units may employ one or many of the following strategies:

- Raid, ambush, or direct assault
- Emplace mines or other munitions
- Conduct standoff attacks from air, ground, or maritime platforms
- Provide terminal guidance for precision-guided munitions
- Conduct independent sabotage
- Conduct anti-ship operations (USSOCOM PUB 1, 1996)

b. Special Reconnaissance (SR)

Special reconnaissance is primarily a defensive mission with the main goal of not being seen. The objective is to verify, through visual or other means, information concerning enemy capabilities, intentions, and activities in support of strategic or operational objectives or conventional forces. The SR mission includes the following:

- Target acquisition
- Area assessment
- Post-strike battle damage assessment
- Collect meteorological, hydrographic, geographic, and demographic data (USSOCOM PUB 1, 1996)

c. Foreign Internal Defense (FID)

The primary objective of the FID mission is to assist another government in any action it takes to free and protect its society from subversion, lawlessness, and insurgency. (USSOCOM PUB 1, 1996)

d. Unconventional Warfare (UW)

Unconventional warfare covers a broad spectrum of both military and paramilitary operations. These operations are usually of long duration in enemy-held, enemy-controlled, or politically sensitive territory. This mission includes the following:

- Guerilla warfare
- Indirect acts of subversion
- Intelligence activities
- Evasion and escape. (USSOCOM PUB 1, 1996)

e. Combating Terrorism (CT)

This mission is an offensive measure taken to prevent, deter or respond to terrorism. (USSOCOM PUB 1, 1996) *f. Counter-proliferation (CP)*

The objective of this mission is to seize, destroy, or recover weapons of mass destruction. (USSOCOM PUB 1, 1996)

g. Civil Affairs (CA)

CA missions cover a broad spectrum of activities that establish, maintain, influence, or exploit relations between military forces and civil authorities, in a friendly, neutral, or hostile area of operation. Civil affairs also include activities and functions that are normally the responsibility of local government. (USSOCOM PUB 1, 1996)

h. Psychological Operations (PSYSOP)

PSYSOP missions are conducted to influence or reinforce the emotions, motives, and behaviors of foreign governments, organizations, groups, and individuals. The ultimate objective is to induce or reinforce attitudes and behavior held by foreign nations that are favorable to U.S. objectives. (USSOCOM PUB 1, 1996)

i. Information Warfare/Command and Control Warfare (IW/C2W)

Actions taken to achieve information superiority in support of the national military strategy by affecting adversary information and information systems while protecting U.S. information and information systems. (USSOCOM PUB 1, 1996)

3. Collateral Missions

a. Coalition Support (CS)

Integrate coalition units into multinational military operations by training coalition members on tactics and techniques and providing communications support. (USSOCOM PUB 1, 1996)

b. Combat Search and Rescue (CSAR)

The CSAR mission requires penetration deep within a hostile or denied territory under adverse conditions to recover distressed personnel during wartime or contingency operations. SOF are equipped and manned to perform CSAR in support of SOF missions. SOF can also perform CSAR in support of conventional forces when it does not interfere with the readiness or operation of core SOF missions. (USSOCOM PUB 1, 1996)

c. Counter-drug Activities (CD)

CD missions are similar to FID and UW missions. The objective is to train host nation forces and domestic law enforcement agencies on the critical skills required to conduct individual and small unit operations in order to detect, monitor, and interdict the cultivation, production, and trafficking of illegal drugs targeted for use in the United States. (USSOCOM PUB 1, 1996)

d. Counter-mine Activities (CM)

Reduce or eliminate the threat to noncombatants and friendly military forces posed by mines and other explosive devices by training host nation personnel in their recognition, identification, marking, and safe destruction. CM missions also provide support for counter-mine programs, medical, and mine awareness activities. (USSOCOM PUB 1, 1996)

e. Humanitarian Assistance

HA missions provide assistance of limited scope and duration to supplement or complement the efforts of the host nation, non-governmental organizations (NGO), and private volunteer organizations (PVO). Their objective is to relieve or reduce the results of natural or man-made disasters that might present a serious threat to life or that can result in great damage to property. SOF participation in HA missions has increased dramatically over the past few years. Their rapid deployability, language skills, regional cultural orientation, organic communications, and ability to sustain operations under adverse conditions make them well suited for these types of missions. (USSOCOM PUB 1, 1996)

f. Security Assistance (SA)

The objective of SA missions is to provide training assistance in support of congressionally legislated programs. These programs provide equipment, military training, and other defense-related services through grants, loans, credit, or cash sales in furtherance of national policies or objectives. The primary SOF role in SA missions is to provide mobile training teams and other forms of training assistance. Personnel conducting SA missions are prohibited by law from performing combatant duties. (USSOCOM PUB 1, 1996)

4. Logistics

To support the various potential principal and collateral missions, SOF need adequate logistical support across all ten primary categories of support as listed in Chapter I. The primary responsibility of USSOCOM in support of SOF is to provide unique class VII end-items that cannot be supported by other services. The primary inventory base for the support of SOF worldwide by USSOCOM for these unique class VII end-items is the Joint Operational Stocks (JOS) revolving inventory system.

a. History of JOS

The Joint Operational Stocks were established following Operation Desert Storm in order to provide a common use inventory system across services for SOF unique class VII end-items. The rationale at the time was that many of the SOF unique end-items are very expensive, used infrequently, and issued in small quantities. Therefore, it is not cost effective to purchase enough of each end-item (such as night vision goggles) for every SOF unit in all services to have their own inventory. Instead, a more cost effective approach would be to establish a revolving inventory system such that SOF units would borrow the items needed for specific missions, and then return those items to the inventory. When a SOF unit from any service requests an item from the JOS inventory, a check of on hand assets is executed. If enough assets are on hand to fill the request, then assets are issued to meet the request. If not enough assets are available to fill the request, then the total on hand assets are issued and the remaining requirement is "killed". There is no backordering in this system.

b. JOS Today

USSOCOM continues to manage the JOS revolving inventory system, setting policy and determining inventory levels. Currently there are 71 different end-items in the inventory system, totalling 2,345 units, valued at over $14M.

c. JOS Increases

Additional units of items currently in inventory are recommended for purchase based on the annual service level achieved for a particular item. Service level is defined as the number of units issued divided by the total number of units demanded throughout a period. Therefore, an item that experiences a demand of 20 units during a period, but only 10 issues were made, has a service level of 10/20, or 50%. Those items that have the lowest service level are recommended to be bought first. The recommended quantity of each item to buy is determined by the JOS inventory managers making ad hoc judgements based on personal expertise. (USSOCOM meeting, 1998)

d. JOS Budget

As referenced earlier, and as highlighted in appendix (A), the current budget for JOS purchases has been eliminated. The JOS managers believe that this is primarily due to the absence of a methodology for justifying inventory additions to the current items. (USSOCOM Meeting, 1998)

5. Problem Statement

By using a revolving inventory, USSOCOM reduces the total quantities of items that need to be stocked. Current demand patterns, however, have shown that the JOS inventory levels fall short in meeting SOF needs for certain items. USSOCOM recognizes that JOS inventories for some items in the current inventory need to be increased, but USSOCOM has no methodology for determining the level of inventory additions or for identifying how to best allocate limited financial resources to provide the best support to Special Operations Forces, per dollar spent.

In order to ensure future funding for JOS a methodology must be developed to determine feasible inventory levels and to prioritize the purchasing of units of inventory.

B. MARGINAL ANALYSIS

Marginal analysis is a term common in economic analysis. It refers to an evaluation of additional benefit for a given cost. (Heyne, 1990) Sherbrooke describes the benefit realized by adding one more unit of stock to a single-item inventory. It is either measured in terms of increased service level (SL) or a decrease in the expected number of backorders (EBO). The cost is the value of one unit. (Sherbrooke, 1992)

Marginal analysis can be used in developing procedures to manage inventory systems. One example of this is found in the Single Order Quantities Inventory System.

The objective of this procedure is to maximize profit subject to the uncertainty involved in demand. Here, an expected profit equation is developed, and then optimized empirically to obtain the maximum profit relative to the one-time order quantity. The result is a ratio of marginal loss to the sum of marginal loss and marginal profit, which yields an optimized service level. (Tersine, 1994)

Another example where marginal analysis is used to develop procedures to manage an inventory system is Sherbrooke's "Readiness Based Sparing" concept. This concept deals with determining the optimal number of units of various items to hold in inventory in a system where failed units are repaired and returned to the inventory. Here, each unit of each item generates a "delta value", which allows it to be compared or ranked against all the other units. Units with the highest "delta value" are stocked to achieve a minimum "Operational Availability" or meet a maximum budget. The Sherbrooke model is discussed in greater detail in the next section. (Sherbrooke, 1992)

C. SINGLE SITE INVENTORY MODEL FOR REPAIRABLE ITEMS

Sherbrooke's design for the single site inventory model for repairables is the foundation for a number of military applications. The Air Force uses a model called Aircraft Availability Model (AAM), which is used primarily to estimate spares budgets. The Army uses a model entitled Selected Essential-Item Stockage for Availability Method (SESAME) which is used for initial spares budgeting. The Navy uses a model called Aviation Readiness Operation Weapon Systems (ARROWS), which is used for determining the inventory levels of its Aviation Coordinated Allowance List (AVCAL).

Sherbrooke's design begins with the definition of Stock Level (s) (at any given time (t)) as

$$s_{(t)} = OH_{(t)} + DI_{(t)} - BO_{(t)}, \quad (1)$$

where, $OH_{(t)}$ is the on hand inventory at time (t);

$DI_{(t)}$ is the amount of inventory due in from the repair process at time (t); and

$BO_{(t)}$ is the number of backorders at time (t).

This definition assumes that once an item fails, the "not ready for issue" (NRFI) item is delivered to a repair facility where it is repaired and returned to the inventory in a "ready for issue" (RFI) condition. Under this scenario, the failure transforms the RFI unit to a NRFI unit; the NRFI unit is sent to a repair facility which increments the DI quantity by one; simultaneously, a requisition is generated and either filled by an on hand asset, thus decrementing the OH quantity by one, or it is placed on backorder, thus incrementing the BO quantity by one, assuming that failures can always be fixed. The net result is that s remains a constant quantity.

Sherbrooke shows that the Expected Fill Rate (EFR) and Expected Backorders (EBO) for a specific item are functions of s. EFR is defined as the expected number of units issued for a particular item at a given stock level divided by the number of units requested for that item. EBO is defined as the expected number of units requested for an item, but not issued due to zero on hand assets at the time of request, for a given stock level; the request for the units will be filled once stock replenishment occurs. He computes the EBO for a range of s for two items, then computes the marginal decrease in EBO per dollar (called the delta value), for the two items using equation (2).

$$\text{Delta value} = [(EBO_{(s-1)} - EBO_{(s)})/C], \quad (2)$$

where C is the cost of a unit of each item. He rank orders all the delta values from highest to lowest, thereby producing a "shopping list". He defines the Expected Backorder of the "system" to be the sum of EBO of each item given their respective stock levels. From this data a cost curve representing system EBO versus cost is generated. Refer to Appendix B.

From this curve, Sherbrooke shows the expected backorders in a given system will decrease, at a decreasing rate, as inventory units are added to the system. His marginal analysis technique results in diminishing decreases of system Expected Backorders as units are added to inventory. Or, another way of looking at it would be a diminishing increase in system effectiveness. With this procedure a decision-maker can decide which units should be chosen from the shopping list, based on either a budget constraint or a maximum acceptable level of EBO.

Sherbrooke discusses the relevance of weighting inventory items based on an item's essentiality regarding the item's importance to missions. This weighting factor can be applied to equation (2) to provide the decision maker with a prioritized listing that takes into account the marginal difference in expected backorders, the cost of an item, and the mission importance or usefulness of an item. Sherbrooke, however, does not implement this methodology, with no reason given. (Sherbrooke, 1992)

1. Laforteza Thesis

Laforteza expands on the Sherbrooke model by incorporating the criticality of items as determined by survey responses to determine which repair parts to stock based on their support to major end items. The formula used by Laforteza is,

$$W*[(EBO_{(s-1)} - EBO_{(s)})/C], \qquad (3)$$

where the additional term W corresponds to the "priority" determined from survey responses. (Gue, 1999) The rationale behind applying the weighting factor is to further discriminate between which units to include in an inventory for a deployed Marine Expeditionary Unit, based on the relative "priority", or criticality, of different items. (Laforteza, 1997)

2. Marginal Analysis of Service Level

Sherbrooke chooses EBO instead of EFR in his marginal analysis technique for two reasons. First, backorders measure the duration of shortages, while fill rates (or service level) only measures what happens when demands occur. Second, Sherbrooke shows that the Operational Availability (Ao) of end items is a function of EBO, where Ao is expressed as a percentage of the time an end item is fully operable. Sherbrooke proves that minimizing EBO maximizes Ao. Thus, Ao can be calculated for a given mix of stock levels of various items, giving a decision-maker another valuable performance measure to assess for a given budget; the decision-maker can also assess the budget for a given Ao target. (Sherbrooke, 1992)

The JOS inventory system of the Special Operations Forces behaves differently than Sherbrooke's inventory system in that JOS sustains no backorders. As stated previously, all demands are either "filled" or "killed" (equivalent to a "lost sale"). Also, JOS items are end items themselves, not repair parts supporting end items. Therefore, service level (SL) is the logical performance measure on which to conduct marginal analysis in the JOS system, where SL is expressed as the percentage of the ratio of units requested to units issued.

In this system, the stock level (s) is equivalent to Sherbrooke's. That is,

$$s = OH + DI, \qquad (4)$$

where s is the stock level; OH is the number of units of an item available to issue; and DI is the total number of units of an item on loan to a SOF unit. The loaned items are expected to be returned when their mission is completed. Therefore, for any stock level (s), for any item, the Service Level for that item is defined as

$$SL_{(s)} = \text{Units Issued/Units Requested} \quad (5)$$

Hence, the marginal value used in this section is defined as

$$\text{Marginal Value} = [(SL_{(s+1)} - SL_{(s)})/C], \quad (6)$$

where $SL_{(s)}$ is the Service Level achieved with (s) units in stock, and $SL_{(s+1)}$ is the Service Level achieved with (s+1) units in stock. The difference $SL_{(s+1)} - SL_{(s)}$ is the marginal increase in service level when adding one more unit to the stock level; and C is the cost of one unit of an item.

3. Percent Marginal Increase in Service Level

There is a problem associated with using equation (6) in marginal analysis of the JOS inventory system. The marginal increase in service level does not appear to be monotonically decreasing. In fact, the marginal increase in service level appears to follow a linear function for most of the JOS items, based on the historical demands. This infers that changes are relatively constant. Appendix C plots service levels for five items. Because there is virtually no change in the difference in service level, applying equation (6) results in units of items being grouped together on the "shopping list"; the model will select most, if not all, units of one item before it begins selecting most, if not all, units of another.

To mitigate this problem this thesis proposes the following equation, which is interpreted as the percent marginal increase in service level (PMISL):

$$PMISL = [(SL_{(s+1)} - SL_{(s)})/SL_{(s)}]/C. \quad (7)$$

See appendix D for an example of these calculations.

Equation (7) is equivalent to equation (6) multiplied by a "weighting factor", i.e., the reciprocal of the $SL_{(s)}$. This weighting concept is inspired by the theory of diminishing returns. The theory of diminishing returns states that the added benefit, or usefulness of each unit of inventory does not increase linearly. Rather it increases at a decreasing rate. Turgot first introduced the principle of diminishing returns in 1767. (Fare, 1980) Turgot stated that, "As equal quantities of capital and labor are applied successively...further application will result in steadily decreasing product increments tending toward zero". (Fare, 1980) Turgot refers to labor and crop production, whereas this thesis discusses inventory items and contribution to mission, but the principle is the same. As inventory is added to an item's stock level, the incremental or marginal contribution of each additional unit of inventory is relatively less than the contribution of the unit added just prior; this diminishing contribution will continue, until additional units essentially contribute nothing to a mission.

This concept is used by Crary in developing the mission effectiveness as a function of effective ships assigned (Crary, 1999). Crary cites that as additional ships are assigned to a mission they only marginally improve effectiveness, and at a decreasing rate as additional ships are added, until a point when additional ships provide no additional benefit. The analogy is more apparent in this case, since in essence ships are end items used to support a particular mission, much as JOS inventory items are end items used to support particular missions.

4. Weighted Percent Marginal Increase in Service Level

In view of Sherbrooke's discussion of a criticality factor and Laforteza's application of this factor this thesis proposes another formula which can be described as a Mission Usefulness, Weighted Percent Marginal Increasing Service Level (WPMISL).

The formula takes equation (7) and multiplies it by a mission usefulness (W) factor as follows:

$$WPMISL = [(SL_{(s+1)} - SL_{(s)})/SL_{(s)}]*[W/C]. \qquad (8)$$

The term "mission usefulness" is equivalent to the term "criticality" applied by Laforteza. There are several approaches that can be taken to determine an item's relative mission usefulness. One such approach allows the decision-makers to rely on their own judgement to make pair-wise comparisons among the inventory. Another allows the ranking of items based on relative demand volume, making the assumption that those items that are demanded most frequently are the most critical. Another method is to collect expert opinions through some sort of survey technique, and then determine an appropriate method for analyzing the survey responses, thereby computing the relative criticality of an item based on the results from the survey. In this thesis a survey of the users of the inventory is used.

D. SUMMARY

Overall, the rationale for evaluating which units of which items to select for purchase using a prioritized listing of WPMISL is based on an adaptation of the methodology of marginal analysis developed by Sherbrooke. This method uses the concept of the relative increase in mission usefulness gained for each additional unit of each item, based on the concept of diminishing returns, measured by the decreasing relative increase in percent service level achieved by each additional unit. Further, this method uses the relative absolute mission usefulness of each item in the inventory and the cost of each additional unit of each item.

III. MODEL DEVELOPMENT

This chapter begins with a discussion of the Excel Workbook, and how the stock records and shopping list are developed. It describes the methodology of computing the projected service levels, and then details the method of developing the mission usefulness weighting factor.

A. EXCEL WORKBOOK

The software employed to generate the prioritized shopping list discussed in the previous chapter is Microsoft EXCEL^{tm}. Within the workbook are 37 worksheets; one worksheet is a command screen worksheet providing quick access to all other worksheets; each of the 35 end items in the JOS inventory has a worksheet listing the stock record; and the remaining worksheet represents the actual shopping list. Various EXCEL^{tm} macros written in VISUAL BASIC^{tm} are used to perform calculations and link the individual stock records to the shopping list. Examples of the command screen worksheet, a stock record, and the shopping list are found in Appendices E through G, respectively.

1. Stock Record

The stock records contain all inventory data associated with the end item. These include demand history, unit cost, and historical service levels. In addition, simulated service levels are obtained for each stock level state. The simulated service levels are generated by sequentially adding one more item to the stock level using historical demands. Finally a column representing the WPIMSL for each stock level state is generated. A detailed description of the data elements of the worksheet is found in Appendix F.

Each stock record card is easily accessible within the workbook, through the command screen worksheet. For each stock record card the user must build in the demand data. Other critical data fields populated by the user are the cost, the current stock level (all units on hand or on loan), and the mission usefulness weight. Once populated, EXCEL^{tm} begins a series of calculations.

The first calculation in the series calculates historical service level by summing all the units issued and dividing by the sum of all the units demanded throughout the historical demand period (either 12 months or 36 months). After the historical service level is computed, EXCEL^{tm} executes a series of macros to compute simulated service levels for various states of stock level (these details are discussed in the next section). Once complete, EXCEL^{tm} computes the WPIMSL for each stock level state using equation (8). After computing the WPMISL for each unit of each item, the shopping list is then developed.

2. Shopping List

EXCEL^{tm} macros are embedded in the workbook to generate the shopping list worksheet. All macros are activated from the command screen worksheet. One macro "cuts and pastes" a table of generated values from each item worksheet onto the shopping list worksheet for consolidation prior to prioritization. The table contains the item number column, the WPIMSL column, and the unit cost column of the item. Another macro sorts these columns by WPIMSL, from largest to smallest, then assigns a rank value for each ordered WPIMSL. The largest WPIMSL is assigned a "1"; the next largest is assigned a "2"; and so forth. Finally a column is developed which maintains a cumulative total of the costs associated with the sequentially ranked columns.

B. SIMULATED SERVICE LEVEL

As noted in equation (8) service level (SL(s)) is a major parameter used in the study. The workbook is "programmed" to compute simulated service levels for each additional unit of stock for each of the 35 items in the study. Key to this process is the actual stock level and the computation of actual service level. Once these two parameters are established a value is calculated which determines an "upper bound" on the number of simulated assets to add to the stock level. Next, three columns are generated, one for the sequential number of assets to add to the stock level, another to compute the simulated service level, and the last to calculate WPIMSL.

The first column represents the additional assets to the original stock level. The first cell in the column is always zero. That is because the cell represents the initial stock level. Then assets are sequentially displayed until the last cell in the column represents a maximum stock level (discussed below). Once this column is completed, a macro will compute the corresponding simulated service level, based on the actual demand pattern. Then equation (8) is used to calculate the WPIMSL.

1. Determination of Upper Bound

In order to apply the methodology in determining the simulated service level for each additional unit of inventory added for each item it is appropriate to determine a reasonable upper bound of inventory units to add to trigger the simulation to stop. Also, establishing an upper bound figure for each item allows the decision-maker to readily evaluate the total cost to purchase all recommended additional units for each item.

To determine a reasonable upper bound several factors must be taken into account. They are variable arrival times of demands, variable demand quantities per demand, and variable loan times. All these factors influence what the appropriate inventory level should be.

The determination of an appropriate upper bound of stock level is derived from the Central Limit Theorem (CLT). The Central Limit Theorem states that the distribution of the sum of independent samples taken from any distribution will tend to the normal distribution as the number of samples becomes large; the normal approximation becomes better as the number of terms in the sum becomes large.

The following variables are used in this procedure:

j = item number

i = a loan for an item

u = number of units

s = stock level of an item (all assets on hand or on loan)

p_j = total period of demand data in days available for item j; $p_j = 365$ or 1096

N_{jpj} = number of loans for item j during period p_j (where a loan is defined as anytime any number of units of the item are issued. So, regardless of whether an issue is made for 5 units or 1 unit, it still counts as 1 loan)

U_{ji}= total number of units requested of item j for loan i

T_{ji} = length of time (in days) of the i^{th} loan for item j

The upper bound is computed using the following terms and expression:

- The Average Loan Time for Each Demand Satisfied for each item ($ALTEDS_j$).

$$ALTEDS_j = \frac{\sum_{i=1}^{Njpj} T_{ji}}{N_{jpj}} \qquad (9)$$

This figure must be computed by the user through accurately recording the duration of each loan period for each item (the T_{ji} values) for demands satisfied (the N_{jp} values). $ALTEDS_j$ is rounded to the nearest integer.

- The Mean Number of Units Demanded During the Average Loan Time for each item ($MNUDDALT_j$). To calculate this value it is first necessary to divide the demand data into sections equal in length to the number of days in an average loan cycle, and then compute the number of units demanded per section for each item j. The average of these values is computed per equations (10) and (11).

Let S_j = number of sections resulting from dividing the demand data for each item j. (Truncated to the integer part.)

$$S_j = pj/ALTEDS_j \tag{10}$$

Define S_{ujd} = number of units of item j demanded during section d, d ranging from 1 to the total number of sections determined by equation (10), where section one begins on day one, and is of length equal to the $ALTEDS_j$ value for that item, section two begins the day after section one ends, and so forth for the number of sections as determined by equation (10).

$$\textit{Then} \quad MNUDDALT_j = \frac{\sum_{d=1}^{S_j} S_{ujd}}{S_j} \tag{11}$$

- The Standard Deviation of the Number of Units Demanded During an Average Loan Time for each item ($SDNUDDALT_j$). This figure is calculated by computing the standard deviation of the number of units demanded per section (the Siuj values) as per equation (12).

$$SNUDDALT_j = \sqrt{\frac{S_j \sum_{d=1}^{S_j} (S_{ujd})^2 - \left(\sum_{d=1}^{S_j} S_{ujd} \right)^2}{S_j(S_j - 1)}} \tag{12}$$

- The Mean Demand Size for each item (MDS_j). The mean demand size is computed by summing all units requested during the demand history, and dividing by the total number of requests as per equation (13).

$$MDS_j = \frac{\sum_{i=1}^{Njpj} U_{ji}}{N_{jpj}} \qquad (13)$$

- The Standard Deviation of Demand Size for each item ($SDDS_j$). This figure is the standard deviation of demand size during the demand history and is computed as per equation (14).

$$SDDS_j = \sqrt{\frac{N_{jpj} \sum_{i=1}^{Njpj} (U_{ji})^2 - \left(\sum_{i=1}^{N_{jpj}} U_{ji} \right)^2}{N_{jpj}(N_{jpj} - 1)}} \qquad (14)$$

- The Current Stock Level (s_j). This figure corresponds to the current stock level (all items on hand or on loan) of each item j, and is required to calculate upper bound values as explained below and in Appendix H.

By the CLT the distribution of the $MNUDDALT_j$ value will tend to a normal distribution, with standard deviation estimated by $SDNUDDALT/\sqrt{S_j}$. Likewise, by the CLT, the distribution of the MDS_j value will tend to a normal distribution with standard deviation estimated by $SDDS/\sqrt{N_{jpj}}$.

Using these values the MNUDDALT term will give an initial estimate of how many units are needed to have in stock as a minimum to cover all demands in an average loan cycle, since as a minimum there should be at least enough to cover the average number of the units demanded in an average loan cycle. MNUDDALT is only a point estimate and does not account for uncertainty inherent in the demand stream. Uncertainty in the demand stream will arise in two primary factors, the arrival stream of demands, and the size of the demands. Therefore to account for uncertainty both in the demand size and the demand frequency the upper bound value is calculated using equation (15) for each item.

$$[(MNUDDALT)+(3*(SDNUDDALT))+(MDS)+(3*(SDDS))]-s=(UB) \quad (15)$$

Appendix H provides a summary table showing all values, (ALTEDS), (MNUDDALT), (SDNUDDALT), (MDS), (SDDS), initial stock level (s), and the resultant upper bound (UB) values for each item determined by application of equation (15). A detailed numerical example is also provided in Appendix H. An analysis of the data reveals that loan times for each item are essentially constant, this allows for the assumption of a constant loan period for each item in the methodology of this thesis.

An alternate methodology for calculation of MNUDDALT and SDNUDDALT is applied and presented in Appendix I. This alternative methodology, using only the simple summary statistics of mean and variance of the times between loans and mean and variance of the size of a loan, has less reliance on the exact pattern of the historical demand stream and is presented as verification of the methodology used. (Jacobs, 1999) The results of the alternative methodology agree well with those of the methodology presented here.

2. Simulated Service Level

The initial service level is the total quantity issued divided by the total quantity requested over the demand history period. After the maximum number of assets to add to the initial stock level is determined, EXCEL^{tm} will simulate a service level for each simulated stock level. (Simulated stock level is defined as the sum of the initial stock level and the number of units to add.) EXCEL™ will determine the simulated number of issues based on the actual historical demand patterns. It will divide this value by the total quantity demanded. This process is accomplished for each stock record. An example of how this process works is provided in Appendix J. The calculation of simulated service levels then allows for the computation of the WPIMSL as per equation (8).

C. MISSION USEFULNESS WEIGHT

Each end item in the JOS inventory contributes to SOF missions. One way of evaluating an item's importance is to determine how often it is used. It is assumed that if an item is "always used" then it is more important to a mission than one that is "very seldom used". This creates a natural ranking of each item based on its relative mission usefulness. To determine the relative mission usefulness of each item a survey of users was conducted. The survey asked respondents to rank the 71 JOS inventory items in one of five categories listed based on frequency of use when performing an expected wartime mission, these categories ranged from "Always Used" to "Very Seldom Used" with a category of "Never Used" assigned to blank responses. The underlying assumption is that those items that are expected to be used most frequently in the performance of a wartime mission are the most useful items when computing relative mission usefulness values. (At the time the survey was conducted it was not known that only 35 items of interest would eventually be considered in the model). The survey was constructed with the assistance of LTC Charles Shaw, U.S. Army, then assigned to the Naval Postgraduate School.

The survey was distributed to the Navy Special Warfare Command in San Diego and given widest dissemination among Naval Special Operations Forces. Likewise, the survey was distributed to the Army Special Operations Forces Command in North Carolina and given widest dissemination among Army Special Operations Forces. An example of the survey is provided as Appendix K.

The survey respondents represent a mix of enlisted and officer personnel from the Army and the Navy. In all, 57 responses were received, 29 from the Navy, and 28 from the Army. Unfortunately, due to the method of distribution of allowing local reproduction and distribution, there is no accounting for the total number of surveys distributed. No attempt to compute different Mission Usefulness weights by service was made since the JOS inventory is designed to provide common support to all services.

To analyze the survey responses, different approaches can be considered. The method used in this thesis is a relatively simple method of assigning ordinal values of "0" through "5" to the six survey response categories. The cumulative responses for each item in each category are multiplied by the ordinal value of that category and summed to yield a "ranking score" for that item. (Agresti 1996) The "ranking scores" of each end item are "normalized" by dividing the score by the largest ranking score computed. This value is now defined as the relative mission usefulness weight, which ranges from 0 to 1. These values are then multiplied by 100 to produce values on a scale of 0 to 100, simply for ease of interpretation by the user. Table 1, equations (16) and (17), and the following example summarizes the methodology:

Item #	Always Used	Frequently Used	Occasionally Used	Seldom Used	Very rarely Used	Never Used	Total ranking score	Normalized Relative Mission Usefulness
1	2	2	2	1	13	37	39	21

Table 1: Sample values for Normalized Relative Mission Usefulness example calculations

The calculations are as follows:

Total Ranking Score = "Always Used" responses * 5 + "Frequently Used" responses * 4 + "Occasionally Used" responses * 3 + "Seldom Used" responses * 2 + "Very Rarely Used" responses * 1 + "Never Used" responses *0 (16)

In this example the "ranking score" is,

(2*5) + (2*4) + (2*3) + (1*2) + (13 *1) = 39. (17)

An item's (Normalized) Relative Mission Usefulness is equal to the Total Ranking Score for the item divided by the largest Ranking Score attained by an item in the survey, multiplied by 100. For this example, given that the largest Ranking Score is 190, the relative Mission Usefulness is,

(39/190)*100 = 21 (rounded to nearest integer value) (18)

This method is chosen for this study for two primary reasons. First, it is easy to compute. Second, it will allow the user a simple method to rank new items by simply collecting similar survey data for that item.

IV. RESULTS

Having built in all necessary data elements into each stock record card in the EXCEL^{tm} workbook, the results for the Simulated Service Levels, the Recommended Quantity to Add based on upper bound calculations, and the WPMISL values are generated by EXCEL^{tm}. The results of each calculation for this study are discussed in a separate section below.

A. MISSION USEFULNESS SURVEY RESULTS

Table 2 summarizes the results of the survey responses concerning mission usefulness for the 35 items of interest. Table 2 also shows the computed values for the normalized relative mission usefulness for the items using the raw data. The values range from 21 to 100. The values for normalized relative item mission usefulness are then posted to each item worksheet in the EXCEL^{tm} workbook and used in the WPMISL computation.

Item #	Always Used	Frequently Used	Occasionally Used	Seldom Used	Very rarely Used	Never Used	Total ranking score	Normalized Relative Mission Usefulness
1	2	2	2	1	13	37	39	21
2	1	4	6	5	12	29	61	32
3	4	2	7	4	6	34	63	33
4	5	5	6	3	10	28	79	42
5	10	12	11	3	5	16	142	75
6	8	12	0	2	9	26	101	53
7	4	1	10	3	11	28	71	37
8	16	9	8	1	4	19	146	77
9	21	10	4	1	5	16	164	86
10	10	11	8	1	6	21	126	66
11	5	9	8	1	9	25	96	51
12	23	11	3	2	6	12	178	94
13	4	3	5	4	10	31	65	34
14	15	21	7	3	4	7	190	100
15	10	11	11	3	6	16	139	73
16	3	8	4	4	15	23	82	43
17	27	10	2	1	3	14	186	98
18	2	4	2	4	9	36	49	26
19	7	7	6	3	6	28	93	49
20	2	3	3	6	11	32	54	28
21	5	5	6	2	11	28	78	41
22	10	10	6	1	9	21	119	63
23	1	3	7	4	10	32	56	29
24	2	5	4	4	12	30	62	33
25	4	5	3	5	10	30	69	36
26	4	9	11	2	10	21	103	54
27	4	4	4	7	10	28	72	38
28	0	0	8	5	8	36	42	22
29	2	5	2	2	10	36	50	26
30	14	17	6	3	9	8	171	90
31	10	12	8	1	10	16	134	71
32	2	9	6	2	11	27	79	42
33	21	11	8	0	5	12	178	94
34	2	2	4	4	10	35	48	25
35	9	10	0	5	9	24	104	55

Table 2: Consolidated raw survey results from Mission Usefulness survey with computed Mission Usefulness weighting values

B. SERVICE LEVEL/STOCK LEVEL RESULTS WITH COST DATA

Table 3 shows the beginning stock level of each item, the current percent service level achieved, the recommended quantity to add based on the upper bound calculations, and the simulated service level achieved when adding the recommended units using the historical demand stream. Several of the items do not achieve a simulated service level of 100% with the recommended additional stock level for the historical demand stream. Several items achieve a simulated service level of 100% at stock levels below the recommended stock level for the historical demand stream. This result does not impact the final recommendation because the purpose of determining the upper bound is used to trigger a stopping of the process of adding additional units, and it is unlikely that the historical demand stream will be repeated. The result of using this method allows EXCEL^{tm} to "look at" only adding 735 units overall. Without this type of upper bound, EXCEL^{tm} would have no stopping point in the computation of WPIMSL values, and as stated before, the upper bound figures provide decision-makers with the maximum recommended additional units for each item. Since USSOCOM's budget for JOS procurement is projected at only $3M over the next five years, and the total cost for the 735 units is $6.8M, the model will select far less than the 735 units.

C. OVERALL WPIMSL RESULTS

As per the methodology developed in Chapter III, and equation (8), individual WPMISL values are generated for each of the 735 recommended additional units. These are consolidated and ordered sequentially in the shopping list worksheet. An excerpt from the shopping list is provided as Appendix G.

Item #	Current Stock Level	Current Service Level	Maximum Recommended Quantity to Add	Simulated Service Level Achieved	Cost per unit in Dollars	Total Cost to add Maximum Recommended Quantity to Add in Dollars
1	2	18	13	94	$60,000	$780,000
2	3	38	5	100	18,500	92,500
3	3	39	5	83	500	2,500
4	10	27	37	89	15,556	575,572
5	31	36	65	89	35,000	2,275,000
6	20	63	26	100	1,865	48,490
7	30	81	18	98	25,500	459,000
8	106	59	30	100	63	1,890
9	15	68	12	100	2,500	30,000
10	73	80	27	95	1,693	45,711
11	25	37	66	89	1,485	98,010
12	262	77	99	86	3,483	344,817
13	2	75	3	100	35,140	105,420
14	162	75	48	86	4,584	220,032
15	12	78	15	100	1,645	24,675
16	20	90	9	100	23,990	215,910
17	20	83	17	100	7,850	133,450
18	5	86	5	100	4,300	21,500
19	34	57	47	81	654	30,738
20	25	87	16	99	2,700	43,200
21	72	80	25	93	5,985	149,625
22	12	83	8	100	11,350	90,800
23	3	92	1	100	4,750	4,750
24	151	94	1	95	803	803
25	13	94	13	100	16,722	217,386
26	41	54	38	81	1,850	70,300
27	14	90	31	100	14,891	461,621
28	4	82	3	100	17,434	52,302
29	26	95	21	100	3,400	71,400
30	169	99	1	100	13,328	13,328
31	83	97	10	100	6,303	63,030
32	37	97	1	99	3,649	3,649
33	36	98	17	100	1,645	27,965
34	40	99	1	100	635	635
35	70	99	1	100	5,000	5,000
TOTALS			**735**			$6,781,009

Table 3: Recommended Stock Level with Simulated Service Level Results

D. SENSITIVITY ANALYSIS

To evaluate the sensitivity of the results based on the methodology developed, the following approach is taken. First, using a budget of $500,000, the recommended shopping list is generated using the WPMISL methodology as per equation (8). Second, to evaluate the impact of the Mission Usefulness weighting factor, the recommended shopping list is generated using the PMISL methodology as per equation (7). Third, to evaluate the impact of the relative service level, the recommended shopping list is generated using equation (6). Fourth, to evaluate the impact of cost on the results, the shopping list is generated using equation (6), without the cost factor. And lastly, to further evaluate the effect of cost, relative to the factors of Service Level and Mission usefulness, the shopping list is generated using the WPIMSL methodology as per equation (8), but without the cost factor. Table 4 displays the consolidated results obtained when generating the shopping list for the first $500,000 using the five different methods:

Method 1 – Shopping list results generated using the WPMISL as per equation (8)

Method 2 – Shopping list results generated using the PMISL as per equation (7)

Method 3 – Shopping list results generated as per equation (6)

Method 4 – Shopping list results generated as per equation (6) without the cost factor.

Method 5 – Shopping list results generated using the WPMISL as per equation (8) without the cost factor.

The columns for current service level, maximum recommended quantity to add (from Table 3), and unit cost are provided as reference values.

Item #	Method 1	Method 2	Method 3	Method 4	Method 5	Current Service Level	Normalized Relative Mission Usefulness	Maximum Recommended Quantity to Add (Upper Bound)	Cost per unit in Dollars
1	0	1	0	4	5	18	21	13	$60,000
2	5	5	5	1	5	38	32	5	18,500
3	6	6	6	1	3	39	33	6	500
4	5	4	0	6	2	27	42	37	15,556
5	0	0	0	4	0	36	75	65	35,000
6	17	17	17	0	0	63	53	26	1,865
7	0	0	0	0	0	81	37	18	25,500
8	25	25	25	0	0	59	77	30	63
9	11	11	11	0	0	68	86	12	2,500
10	11	11	11	0	0	80	66	27	1,693
11	48	43	63	3	0	37	51	66	1,485
12	0	0	0	0	0	77	94	99	3,483
13	0	0	2	0	2	75	34	3	35,140
14	0	0	0	0	0	75	100	48	4,584
15	8	8	8	0	0	78	73	15	1,645
16	0	0	0	0	0	90	43	9	23,990
17	0	0	0	0	0	83	98	17	7,850
18	1	1	1	0	1	86	26	5	4,300
19	48	48	48	0	0	57	49	48	654
20	0	0	2	0	0	87	28	16	2,700
21	0	0	0	0	0	80	41	25	5,985
22	1	0	1	0	0	83	63	8	11,350
23	1	1	1	0	0	92	29	1	4,750
24	2	2	2	0	0	94	33	2	803
25	0	0	0	0	0	94	36	13	16,722
26	39	26	26	0	0	54	54	39	1,850
27	0	0	0	0	0	90	38	31	14,891
28	1	1	1	0	0	82	22	3	17,434
29	0	3	3	0	0	95	26	21	3,400
30	0	0	0	0	0	99	90	1	13,328
31	0	0	0	0	0	97	71	10	6,303
32	0	0	2	0	0	97	42	2	3,649
33	2	2	2	0	0	98	94	17	1,645
34	1	1	1	0	0	99	25	1	635
35	0	0	0	0	0	99	55	1	5,000

Table 4: Shopping list consolidation summary table for five different budget allocation methods, indicating the number of units per item each method recommends, given a budget of $500,000.

The results of the sensitivity analysis reveal several interesting points. First it is apparent that the first three methods have very similar results, and the fourth and fifth methods have similar results, but very different from methods one, two, and three. These results indicate two things primarily. First, if cost is a consideration, it is by far the most significant factor involved when making purchasing decisions, even when the factors of Service Level and Mission Usefulness are taken into consideration. This is clearly indicated by the contrasting results between methods one, two, and three, all of which consider cost, and methods four and five, which do not consider cost. Second, when cost is not a consideration, Service Level tends to be the most significant factor as opposed to Mission Usefulness. This is indicated by the similarity in the results between methods four and five; the inclusion of the Mission Usefulness weighting factor had only minimal impact.

A more detailed analysis of the differences generated between Method 1 and Method 2 reveals some impact of the Mission Usefulness weighting factor. Specifically, Method 1, which considers the weighting factor, chooses zero of item one and 39 of item 26. In contrast, Method 2, which does not consider the weighting factor, chooses one of item one and only 26 of item 26. This indicates that the application of the Mission Usefulness weighting factor results in shifting the priority away from item one with a very low Mission Usefulness value, and towards item 26 with a higher Mission Usefulness weighting factor of 54. This type of "shifting priorities" is exactly what should be expected from the application of the Mission Usefulness weighting factor, so it is encouraging to see these results. However, comparing all values of Method 1 with all values of Method 2 indicates that very little "priority shifting" occurred. In fact, of the 35 items, only 5 show any variation in results between the two methods. This is an indication of how minimal an effect the Mission Usefulness weighting factor has on the results.

Another interesting comparison is between the results produced by method 1, using the WPIMSL metric, and the results produced by method 5 using the WPIMSL metric without the cost factor. Immediately it is apparent that method 5 chooses five of item one, priced at $60,000, and method 1 chooses none of the same item. This is an indication of the influence of the cost factor. But what if item one has a very high Mission Usefulness weight, maybe it would be purchased by method one as well? Looking at items 12, 14, and 17, all with very high Mission Usefulness values of 94, 100, and 98 respectively, none of these items are recommended for purchase. This is further indication that Mission Usefulness has little impact on the WPMISL rankings.

Lastly, another indication of just how strong the cost driver is in the methodology is found by looking at the results of item 34. Overall item 34 is ranked 33rd of the 35 items in terms of mission usefulness. The current Service Level is 99%, and the recommended quantity to buy is only one, all indications that item 34 should probably not be one of the first items bought. Yet, all three methods that consider cost, Method 1, Method 2, and Method 3, each method recommends purchasing item 34. This result is clearly due to the fact that item 34 has a very low relative cost as compared to other items in the study.

E. SUMMARY OF RESULTS

Table 4 shows that despite the detailed methodology developed in this thesis to rank items based on the metric of WPMISL, the methodology is predominantly cost driven. Indeed, as Table 4 shows, generating the shopping list without applying the Mission Usefulness weighting factor or adjusting for the relative increase in Service Level has almost negligible effects on the results when compared to the results generated when both factors are included. Although the impact of the Mission Usefulness weight is minimal, it does have some effect and should not be completely disregarded. A thoughtful decision-maker will assess the results achieved when cost is a factor, compare with the results when cost is not a factor, and then evaluate the Mission Usefulness weighting factor. This allows for human intelligence to determine whether or not to adjust the recommended prioritized listing sequence. A good example of this deals with item 1. When cost is removed from the prioritization as is done in Methods 4 and 5, the recommendation is to purchase at least four of these items at $60,000 each. A decision-maker might not want to accept this because this item has the lowest mission usefulness value of all 35 items. A purchase of four of these items represents almost half of the $500,000 budget.

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V. CONCLUSIONS AND RECOMMENDATIONS

> We will have to make hard choices to achieve the tradeoffs that will bring the best balance, most capability, and greatest interoperability for the least cost.
>
> Joint Vision 2010

A. GENERAL

The results indicate that the methodology developed and applied in this thesis provides a reasonable tool for the decision-maker to decide how to allocate limited funds to provide maximum support for missions. However, as the sensitivity analysis shows, not all terms used in the measure of effectiveness are influential in prioritizing the items to purchase. The most influential is cost. The efforts necessary to compute relative Mission Usefulness values for items, as compared to the influence these values have on the final results indicate the efforts are not justified. Further, the Mission Usefulness values provided by this thesis should not be considered definitive since the Mission Usefulness value is subjective and is based on respondents perceived need for items based on their understanding of missions they may be required to perform. If a decision-maker has specific knowledge of anticipated missions that require particular items in the JOS inventory, this knowledge should take precedence over the relative Mission Usefulness values provided in this thesis.

Primarily a decision-maker should evaluate the results from the WPMISL methodology as another input into the difficult process of deciding what items to buy, when funds are limited. The WPMISL results are not optimal results, but rather are results produced based on the application of the methodology in this thesis. Therefore, a reasonable decision-maker can certainly disagree with the prioritized listing produced by the WPIMSL methodology. However, in disagreeing with the WPMISL results, a decision-maker should be able to provide reasons why his/her prioritization is preferred.

B. RECOMMENDATIONS FOR FURTHER STUDY

1. Additional methods to compute relative mission usefulness

Although the methodology developed in this thesis tends to indicate that relative Mission Usefulness among items in the JOS inventory has minimal impact on prioritizing recommended purchases, this does not invalidate the basic premise that it is reasonable to make decisions regarding inventory purchases based on what the expected contribution to an expected mission an inventory purchase will make. Indeed, with typically inadequate funding to purchase all anticipated inventory requirements, methodologies to prioritize inventory purchases need to be developed. Therefore, additional weighting schemes and mission usefulness measures should be explored and evaluated to determine if they are reasonable and if they have any impact on the recommended prioritization of inventory purchases.

2. Additional methods to compute recommended stock level

This thesis computes a recommended stock level based on raw historical demand. The underlying assumption is that the demand stream is does not have much variability, and that current demand streams closely resemble that which would be experienced in the future. If, however, a decision-maker has knowledge that demand streams are going to change, then this knowledge should be factored in to the determination of the recommended stock level. Also, if an analysis of expected missions indicates that current demand streams do not reflect expected demand in the performance of contingency missions, then a determination needs to be made regarding setting stock levels based on current demand, or based on potential wartime demand.

USSOCOM has developed a database of all anticipated contingency scenarios and the expected SOF response, including anticipated JOS inventory items required. An assessment could be made regarding the probability of any of the scenarios occurring, and then a stock level could be recommended to provide a level of confidence that there will be adequate stocks to meet anticipated contingency scenarios.

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APPENDIX A. CDR FRANCIS TISAK POINT PAPER

CDR Tisak
SOAL-LS, 8-8246
17 November 1998

SUBJECT: Impact of Loss of FY99 Procurement Funding from Joint Operational Stocks (JOS)

1. Purpose: This statement addresses the impact of losing FY99 Procurement Funding from the Joint Operational Stocks (JOS) Program.

2. Major Points:
   - JOS provides SOF with a pool of equipment to meet a variety of special operations missions
   - JOS directly supports USSOCOM components and theater SOCs
   - JOS enhances SOF missions with specialized, SO-unique equipment
   - JOS is an operational asset in continuous use by SOF units throughout the world in support of real-world, contingency and training missions
   - The JOS Project is currently underfunded; cutting FY99 procurement funding will exacerbate this problem and diminish support to the SOF warfighter in the field
   - Recent AE guidance seeks to reestablish current JOS funding shortfalls

3. Discussion: JOS provides joint SOF units access to selected SO mission enhancing equipment for real-world, contingency and training missions while conserving scarce USSOCOM resources. During FY98, JOS satisfied 309 loan requests to SOF forces deployed worldwide in support of theater SOC requirements.
While the JOS pool encompasses several different categories of equipment, recent demand data indicates that man-pack communication systems comprise our top requirement. With a current shortfall of over 120 man-pack communication systems, this year's JOS procurement funding was earmarked to partially fill this critical need. Any loss in FY99 JOS procurement funding reduces our ability to satisfy this heavily demanded mission-critical requirement.

With the exception of funding in FY01 to procure generators and Environmental Control Units, recent USSOCOM budgetary decisions have eliminated procurement dollars from the POM for JOS beginning FY00. Without procurement dollars it will be extremely difficult to keep the JOS program viable. Losing FY99 procurement dollars exacerbates this problem.

The JOS concept, a force multiplier, has proven to be extremely responsive and operationally effective. Moreover, JOS maximizes the use of limited MFP-11 resources while providing SOF customers quick reaction access to well maintained state of the art equipment. SOF units appreciate the service that JOS provides; reductions to this project will limit the SOF warfighter's flexibility and impact our ability to enhance mission readiness.

4. Recommendation: Do not subtract any FY99 Procurement Funding from the JOS Program.

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APPENDIX B. NUMERICAL EXAMPLE USING SHERBROOKE METHODOLOGY TO PRIORITIZE ADDITIONAL UNIT PURCHASES BETWEEN TWO ITEMS OF INVENTORY.

Table 5 generates the Expected Backorders (EBO) for two inventory items at various stock levels assuming Poisson demand, and the parameters given using the formula given in Sherbrooke, 1992. Table 6 generates the marginal increase in system effectiveness per dollar values based on the expected backorder values and cost data from Table 5.

Item	1	2
Mean annual demand (m)	10	50
Average repair time (T)	.1	.08
Average pipeline (υ = mT)	1	4
Item cost ($000)	$5	$1
s	EBO(s)	EBO(s)
0	1.000	4.000
1	.368	3.018
2	.104	2.110
3	.023	1.348
4	.004	.782
5	.001	.410
6	.000	.195
7	.000	.085
8	.000	.034
9	.000	.012
10	.000	.004

Table 5: Expected backorders for two items

s	Item 1 [Cost ($000)=5]		Item 2 [Cost ($000) = 1]	
	EBO(s)	EBO(s-1)-EBO(s) / 5	EBO (s)	EBO(s-1)-EBO(s) / 1
0	1.000		4.000	
1	.368	.126	3.018	.982
2	.104	.053	2.110	.908
3	.023	.016	1.348	.762
4	.004	.004	.782	.567
5	.001		.410	.371
6	.000		.195	.215
7	.000		.085	.111
8	.000		.034	.051
9	.000		.012	.021
10	.000		.004	.008

Table 6: Marginal increases in system effectiveness for two items

Thus, in Table 6 the total expected backorders EBO(s) before any stock is purchased are 1.000 + 4.000 = 5.000. The deltas for the first spare of item 1 and item 2 are .126 and .982 respectively, so item 2 is selected and total backorders drop to 1.000 + 3.018 = 4.018. Moving down to the second spare of item 2, and comparing deltas of .126 and .908. Again item 2 wins and after adding the second spare of item 2 the total backorders are 1.000 + 2.110 = 3.110. The first six comparisons all result in the selection of item 2, after which the delta of .126 for item 1 exceeds .111 for the seventh spare of item 2, so the first unit of item 1 is added next. The result is the system backorder versus cost curve as displayed in Figure 1. (Sherbrooke, 1992)

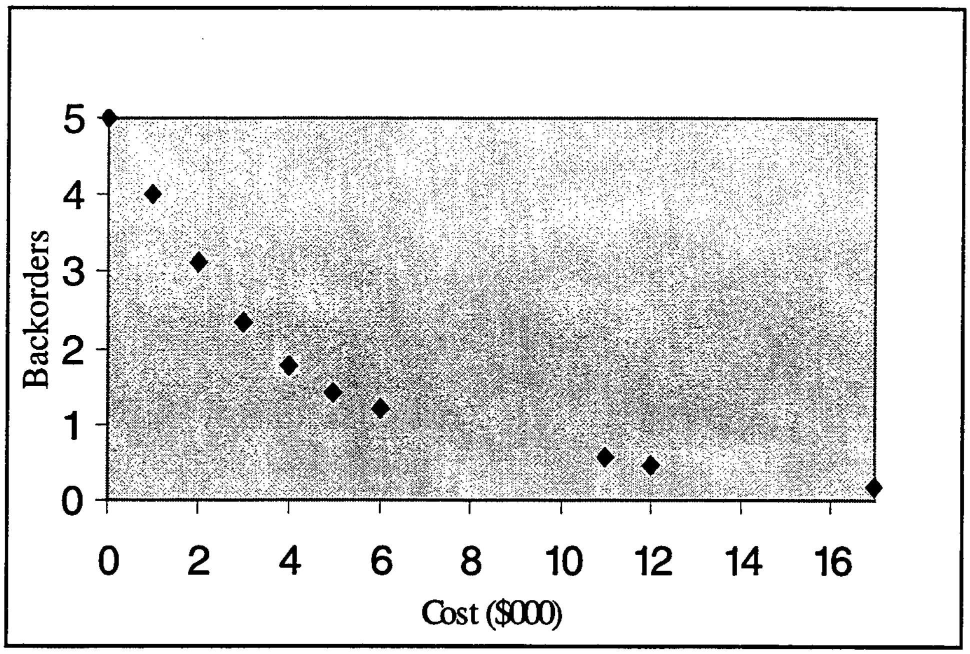

Figure 1: Optimal system backorders vs. cost

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APPENDIX C. GRAPHICAL REPRESENTATION OF SIMULATED SERVICE LEVEL FOR ADDITONAL UNITS

Using five of the items from the study as an example (items 4, 10, 17, 19, and 26), Figure 2 below shows a linear trend of increasing simulated service levels as units are added to stock.

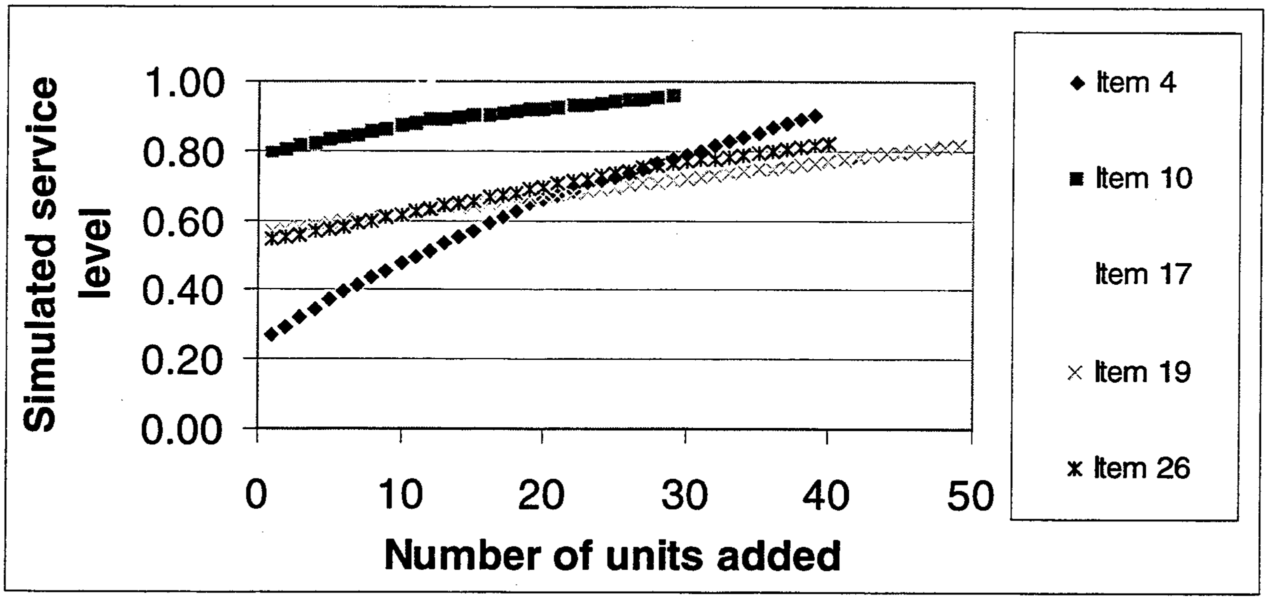

Figure 2: Simulated Service Level for five items as units are added to stock

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APPENDIX D. NUMERICAL EXAMPLE COMPUTING PERCENT MARGINAL INCREASE IN SERVICE LEVEL VALUES (PMISL)

The following example demonstrates the methodology applied in this thesis for the computation of the percent marginal increase in service level provided by the addition of one unit of stock for a particular inventory item.

The equation used to compute the PMISL is:

$$PMISL = [(SL_{(s+1)} - SL_{(s)})/SL_{(s)}]/C \qquad (7)$$

In this expression Service Level ($SL_{(s)}$) corresponds to the simulated service level achieved for the particular item given a stock level of (s); Service Level ($SL_{(s+1)}$) corresponds to the simulated service level achieved for the particular item given a stock level of (s+1); the cost corresponds to the cost in dollars of one unit of inventory for the particular item. (The methodology on how to compute simulated service levels is provided in chapter III.)

Using the numerical data for simulated service levels computed in Tables 11-13, in Appendix G, for one, two, and three units added to inventory item A; and assuming a per unit item cost of $5,000, the following PMISL values are calculated using equation (6) and displayed in Table 7.

Item: <u>A</u> Initial Stock Level: **<u>10</u>** Initial Service Level Achieved: **<u>80%</u>**

Number of Units Added to Inventory	Simulated Service Level Achieved	PMISL
0	80	0
1	88	[1] 20.0×10^{-6}
2	96	[2] 18×10^{-6}
3	100	[3] 8.3×10^{-6}

Table 7: Computed marginal increase in mission usefulness per dollar values

Value 1 is calculated as follows, as per equation (7):

$$[(88-80)/80]/5000 = .00002 \text{ or } 20.0 \times 10^{-6}$$

Value 2 is calculated as follows, as per equation (7):

$$[(96-88)/88]/5000 = .000018 \text{ or } 18 \times 10^{-6}$$

Value 3 is calculated as follows, as per equation (7):

$$[(100-96)/96]/5000 = .0000083 \text{ or } 8.3 \times 10^{-6}$$

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APPENDIX E. EXAMPLE OF COMMAND SCREEN

Figure 3 is a "snapshot" of the EXCEL^{tm} command screen used in the workbook to generate the shopping list. Each item number command button links to the worksheet representing the stock record card for that item number, the shopping list command button links to the final prioritized shopping list worksheet; and the Generate Shopping List command button will generate the prioritized shopping list as per the methodology developed within this thesis.

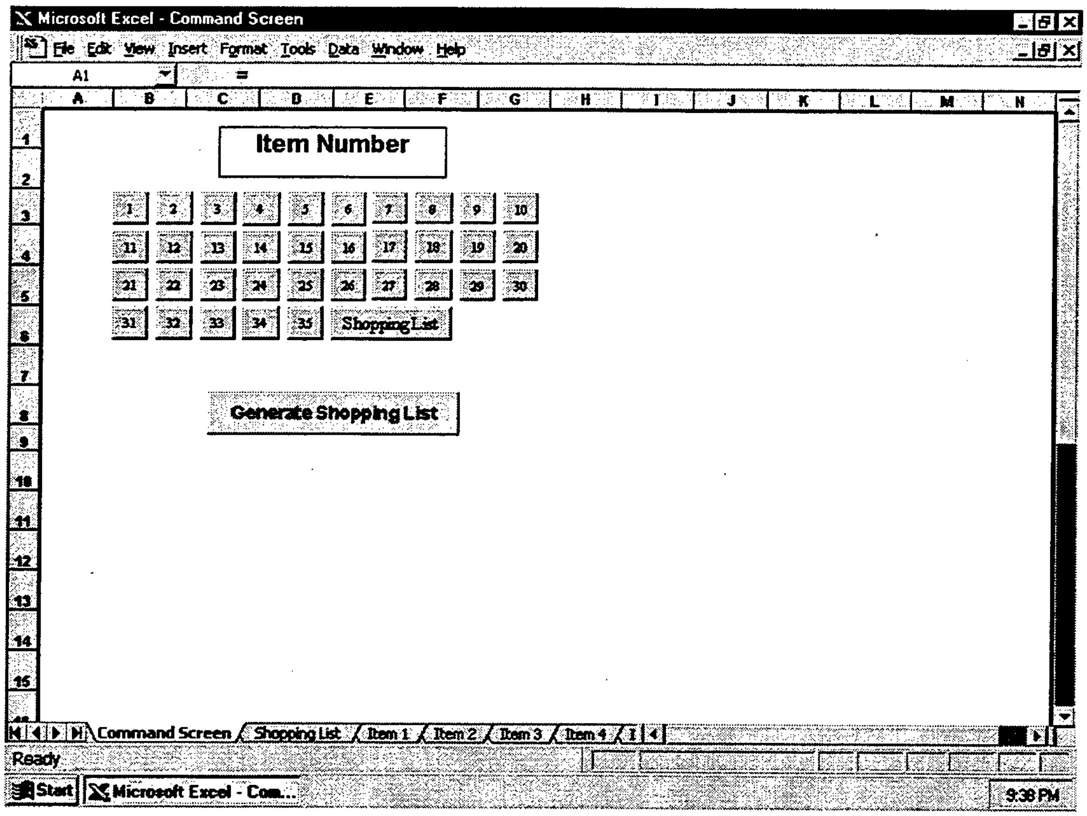

Figure 3: "Snapshot" of command screen worksheet

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APPENDIX F. EXAMPLE OF A STOCK RECORD CARD

To develop the EXCEL™ workbook this thesis employs a standardized template worksheet for each item that is then replicated for all items in the inventory. The template design captures all the relevant information for each item. Figure 4 shows the template design using one of the items as an example, with detailed data entry descriptions following.

	A	B	C	D	E	F	G	H	I
1			CACHE LOCATING DEVICE				Item #	3	
2			Stock Level	3	Mission Usefulness	43	Number of items to add	5	
3			Cost	**$500**	3 Year service level	**0.387**			
4	DATE	Quantity Returned	Stock on Hand	Quantity Requested	Quantity Satisfied	Units Demanded During Average Loan Time	# of items added	Simulated Service Level	WPMISL
5	96001		3		0	4	0	0.387	0
6	96002		3		0	1	1	0.516	286.67
7	96003		3		0	2	2	0.612	161.25
8	96004		3		0	0	3	0.709	135.79
9	96005		3		0	0	4	0.774	78.18
10	96006		3		0	4	5	0.838	71.67
11	96007		3		0	1			
12	96008		3		0	1			
13	96009		3		0	1			
14	96010		3	1	1	1			
15	96011		2		0	2			
16	96012		2		0	0			
17	96013		2		0	2			
18	96014		2		0	0			
19	96015		2		0	2			
20	96016		2		0	2			
21	96017		2		0	2			
22	96018		2		0	1			
23	96019		2		0	0			
24	96020		2		0	2			
25	96021		2		0	1			
26	96022		2		0	0			
27	96023		2		0	2			
28	96024		2		0	0			
29	96025		2		0				
30	96026		2	1	1				

Figure 4: Stock record card template

1. The detailed stock record card procedures and entries are as follows:

a. The Item Name (Cell C1) is entered by the user, and is the common item nomenclature for the particular item.

b. The Item Number (Cell J1) is entered by the user, and is used as a reference to identify particular items when constructing the prioritized listing of recommended purchases.

c. The Stock Level (Cell D2) is entered by the user, and this is the stock level on hand at the beginning of the period. All sheets begin with Fiscal Year 1996 day 1.

d. The Mission Usefulness Value (Cell F2) is computed based on the methodology described in Chapter III and Appendix H to evaluate survey responses.

e. The Number of Items to Add (Cell J2) is a figure calculated based on the methodology described in Chapter III.

f. The Cost (Cell D3) is the current cost of the item, and this figure is a necessary value to be used in the calculation of the Marginal Gain in Mission Usefulness for each additional unit of inventory added.

g. The 3 Year Service Level (Cell F3) is computed by dividing the total Quantity Satisfied by the total Quantity Requested for the entire period, rounded to three decimal places.

h. The Date column is listed in columns A and is used to record demands, issues, and returns. For this workbook three years worth of data is entered.

i. The Quantity Returned column records the day a particular demand is returned. For instance, if a demand is received on day 96085, and is for 40 days, the quantity returned column will reflect a posting on day 96125 that corresponds to the quantity issued on day 85.

j. The Stock on Hand column maintains a running quantity of Stock currently on hand. This value is continually updated by subtracting the Quantity Issued and adding the Quantity Returned as appropriate. So, for instance, the Stock on Hand value for day 96011, will be computed by subtracting the Quantity Satisfied entry on day 96010 from the Stock on Hand Quantity on day 96010, and by adding the Quantity Returned value from day 96011.

k. The Quantity Requested column reflects customer requests on the date of the request for the quantity requested.

l. The Quantity Satisfied column is computed by subtracting the Quantity Requested column from the Stock on Hand column. If the Quantity Requested exceeds the Stock on Hand column, then the Quantity Satisfied is the Stock on Hand for that day.

m. The Units Demanded During Average Loan Time column is computed by first dividing the data set into time increments equal to the average loan time of 46 days (for this item) and then computing the sum of the number of items ordered during each increment. This column is then used to compute MNUDDALT and SNUDDALT.

n. The Number of Items Added column is a count from zero up to the recommended number of items to add from cell J2. This column is used to construct the listing of Simulated Service Level in column H.

o. The Simulated Service Level column is computed by iteratively adding items one at a time to the Stock Level in cell D2 and then computing what simulated service level would have been achieved had that been the original Stock Level using the historical demand, as described in Chapter III. The Simulated Service Level will be computed up to the recommended number of items to add from cell J2.

p. The Cost column records the cost of each additional unit added. It is important to generate a column of costs corresponding to every unit of every item added for use in generating the overall consolidated prioritized listing of units to add; and computing a total running cost.

q. The Item # column references the item # input in cell J1. The item # is used as a reference to identify particular items when constructing the prioritized listing of recommended purchases.

r. The WPMISL for Each Additional Unit column is computed for each unit of each item added as described in chapters II and III. (The WPMISL values are multiplied by 1,000,000 for scaling).

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APPENDIX G. SHOPPING LIST EXCERPT, PRIORITIZED BY WPMISL

Figure 5 shows an excerpt from the final prioritized listing providing a descending rank order structure across all units of all items based on each unit's WPMISL value.

Priority to Add	Item #	WPMISL	Cost of Unit	Total Cumulative Cost	Priority to Add	Item #	WPMISL	Cost of Unit	Total Cumulative Cost
1	8	514.29	$63	$63	51	9	11.00	$2,500	$45,545
2	8	494.51	$63	$126	52	15	10.94	$1,645	$47,190
3	8	476.19	$63	$189	53	11-	10.71	$1,485	$48,675
4	8	459.18	$63	$252	54	9	10.67	$2,500	$51,175
5	8	443.35	$63	$315	55	11	10.42	$1,485	$52,660
6	8	428.57	$63	$378	56	11	10.14	$1,485	$54,145
7	8	414.75	$63	$441	57	11	9.87	$1,485	$55,630
8	8	401.79	$63	$504	58	11	9.62	$1,485	$57,115
9	8	389.61	$63	$567	59	11	9.38	$1,485	$58,600
10	3	286.67	$500	$1,067	60	6	9.29	$1,865	$60,465
11	8	252.10	$63	$1,130	61	6	8.99	$1,865	$62,330
12	8	247.25	$63	$1,193	62	6	8.71	$1,865	$64,195
13	8	242.59	$63	$1,256	63	6	8.45	$1,865	$66,060
14	8	238.10	$63	$1,319	64	19	8.33	$654	$66,714
15	8	233.77	$63	$1,382	65	19	8.25	$654	$67,368
16	8	229.59	$63	$1,445	66	19	8.18	$654	$68,022
17	8	225.56	$63	$1,508	67	11	8.13	$1,485	$69,507
18	8	221.67	$63	$1,571	68	19	8.11	$654	$70,161
19	8	217.92	$63	$1,634	69	6	8.08	$1,865	$72,026
20	3	161.25	$500	$2,134	70	19	8.04	$654	$72,680
21	3	135.79	$500	$2,634	71	19	7.97	$654	$73,334
22	8	107.14	$63	$2,697	72	11	7.96	$1,485	$74,819
23	8	106.26	$63	$2,760	73	19	7.90	$654	$75,473
24	8	105.39	$63	$2,823	74	6	7.85	$1,865	$77,338
25	8	104.53	$63	$2,886	75	19	7.84	$654	$77,992
26	8	103.69	$63	$2,949	76	11	7.79	$1,485	$79,477
27	8	102.86	$63	$3,012	77	19	7.77	$654	$80,131
28	8	102.04	$63	$3,075	78	19	7.71	$654	$80,785
29	3	78.18	$500	$3,575	79	19	7.65	$654	$81,439
30	3	71.67	$500	$4,075	80	6	7.64	$1,865	$83,304
31	3	66.15	$500	$4,575	81	11	7.63	$1,485	$84,789
32	15	27.36	$1,645	$6,220	82	19	7.58	$654	$85,443
33	15	25.92	$1,645	$7,865	83	19	7.52	$654	$86,097
34	9	15.30	$2,500	$10,365	84	19	7.46	$654	$86,751
35	9	14.67	$2,500	$12,865	85	6	7.44	$1,865	$88,616
36	9	14.08	$2,500	$15,365	86	19	7.40	$654	$89,270
37	9	13.54	$2,500	$17,865	87	18	7.36	$4,300	$93,570
38	9	13.04	$2,500	$20,365	88	19	7.34	$654	$94,224
39	9	12.57	$2,500	$22,865	89	11	7.32	$1,485	$95,709
40	15	12.31	$1,645	$24,510	90	19	7.29	$654	$96,363
41	9	12.14	$2,500	$27,010	91	6	7.24	$1,865	$98,228
42	15	12.01	$1,645	$28,655	92	19	7.23	$654	$98,882
43	9	11.73	$2,500	$31,155	93	11	7.18	$1,485	$100,367
44	15	11.72	$1,645	$32,800	94	19	7.17	$654	$101,021
45	11	11.71	$1,485	$34,285	95	19	7.12	$654	$101,675
46	15	11.45	$1,645	$35,930	96	19	7.07	$654	$102,329
47	11	11.36	$1,485	$37,415	97	6	7.06	$1,865	$104,194
48	9	11.35	$2,500	$39,915	98	11	7.02	$1,485	$105,679
49	15	11.19	$1,645	$41,560	99	19	7.01	$654	$106,333
50	11	11.03	$1,485	$43,045	100	19	6.96	$654	$106,987

Figure 5: Excerpt of "Shopping List" showing the prioritization of the first 100 units to purchase

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APPENDIX H. NUMERICAL EXAMPLE COMPUTING STOCK LEVEL UPPER BOUND

The following example demonstrates the methodology applied in this thesis for the computation of the upper bound for the stock level used to generate the WPMISL values based on the addition of one additional unit of stock for a particular inventory item, up to the upper bound.

The following figures for item #3 will serve as an example, (the reader can refer to Figure 4 in Appendix F):

Current Stock Level ------------------------------------ 3 (This value is given in the data and corresponds to (s) in equation(15))

Average loan time -------------------------------------- 46 days. (This value is computed by dividing the total number of days items were on loan by the total number of loans as per equation (9))

Mean number of units demanded in 46 days -------- 1.29 (This figure is the average of the column of numbers found in column F in Figure 4 under the heading Units Demanded During Average Loan Time, this figure corresponds to (MNUDDALT) in equation (11))

Standard deviation of units demanded in 46 days --- 1.16 (This figure is the standard deviation of the column of numbers found in column F in Figure 4 under the heading Units Demanded During Average Loan Time, this figure corresponds to (SDNUDDALT) in equation (12))

Average demand size ---------------------------------- 1.45 (This figure is the average demand size computed over the demand history of the item. It is the average of column D in Figure 4 under the heading quantity requested, this figure corresponds to (MDS) in equation (13))

Standard deviation of demand size -------------------0.83 (This figure is the standard deviation of demand size computed over the demand history of the item. It is the standard deviation of column D in Figure 4 under the heading quantity requested, this figure corresponds to (SDDS) in equation (14))

Then as per equation (15), the recommended upper bound for this item is:

$$[(1.29 + (3 \text{ x } 1.16)) + (1.45 + (3 \text{ x } .83)] - 3 = 5.71 \qquad (15)$$

This figure is then rounded to the nearest integer value, so therefore 6 will serve as the upper bound for number of units to add for item #3 when generating the marginal increase in mission value per dollar figures used in the prioritized listing. Table 8 displays the values and results for all the items in the study.

Item #	Mean Number of Units demanded during average loan time	Standard Deviation of Units demanded during average loan time	Average Loan Time in days	Mean Demand Size	Standard Deviation of Demand Size	Current Stock Level	Calculated Upper bound value
1	1.89	2.75	41	3.09	4.7	14	13
2	0.33	1.13	40	5.33	3.05	13	5
3	1.29	1.16	46	1.25	0.53	2	6
4	8.34	7.98	42	3.88	2.19	10	37
5	15.5	18.5	45	4.08	1.63	30	65
6	10.56	7.67	43	3.96	2.54	19	26
7	16	7.86	43	3.80	2.56	33	18
8	7.67	10.62	34	12.35	8.45	47	30
9	3.78	3.42	35	8.87	6.65	31	12
10	11.33	9.55	36	12.08	8.43	50	27
11	24.67	16.64	46	5.94	3.21	24	66
12	114.11	58.15	47	23.27	14.67	257	99
13	0.22	0.87	38	2.45	3.45	13	3
14	52.56	40.73	47	15.68	10.34	173	48
15	5.11	5.08	34	5.80	3.12	21	15
16	4.44	3.51	39	2.97	4.56	23	9
17	2.22	3.6	45	3.95	2.12	6	17
18	0.78	1.26	44	2.46	1.23	6	5
19	16.44	12.45	40	10.08	13.69	57	48
20	6.44	5.59	49	5.36	3.27	22	16
21	22.56	13.29	32	15.65	11.83	89	25
22	2.67	4.21	36	3.62	5.28	27	8
23	0.11	0.33	38	0.55	1.29	5	1
24	7.22	4.95	46	3.11	3.72	34	2
25	4.11	4.14	41	8.88	4.71	27	13
26	24.56	11.35	40	15.60	9.26	63	39
27	2.11	4.86	46	3.00	4.71	3	31
28	0.56	1.13	42	1.39	0.93	5	3
29	6.22	9.97	38	11.03	5.84	44	21
30	16.11	19	45	13.71	15.67	133	1
31	15.67	8.64	44	3.76	4.55	49	10
32	5.22	4.12	47	3.84	3.24	29	2
33	12.78	15.38	38	10.76	4.59	66	17
34	4.78	3.97	41	3.56	2.12	26	1
35	15.44	8.2	41	4.13	1.59	48	1

Table 8: Applicable factors and results for upper bound calculations

APPENDIX I. ALTERNATE METHODOLOGY FOR COMPUTING MNUDDALT AND SNUDDALT VALUES

Under the assumption that the loan times are constant, the loan requests occur according to a renewal process, and the number of units demanded per request are independent identically distributed random variable independent of the loan times, the following calculations can be used to compute the approximations to Mean Number of Units Demanded During Constant Loan Time and the Standard Deviation of Units Demanded During Constant Loan Time. (Jacobs, 1999)

$$\left[\frac{\text{Constant Loan Time}}{\text{Mean Time Between Loans}}\right] * \left[\text{Mean Demand Size}\right] \approx \left[\begin{array}{l}\text{Mean Number of}\\ \text{Units Demanded}\\ \text{During Constant}\\ \text{Loan Time}\end{array}\right] \qquad (18)$$

$$\left[\begin{array}{l}\text{Constant}\\ \text{Loan}\\ \text{Time}\end{array}\right] * \left(\left[\begin{array}{l}\text{Mean}\\ \text{Demand}\\ \text{Size}\end{array}\right]^2 * \frac{\left[\begin{array}{l}\text{Standard Deviation}\\ \text{of time Between}\\ \text{Loans}\end{array}\right]^2}{\left[\begin{array}{l}\text{Mean Time}\\ \text{Between Loans}\end{array}\right]^3} + \frac{\left[\begin{array}{l}\text{Standard Deviation}\\ \text{Of the size of the}\\ \text{Demand}\end{array}\right]^2}{\left[\begin{array}{l}\text{Mean Time}\\ \text{Between Loans}\end{array}\right]}\right)$$

$$\approx \left[\begin{array}{l}\text{Variance}\\ \text{Of Units Demanded}\\ \text{During Constant}\\ \text{Loan Time}\end{array}\right] \qquad (19)$$

The calculations follow from formulas for the mean and variance of a sum of a random number of independent identically distributed random variables and the approximate mean and variance of the number of renewals (loan requests) to occur during the constant loan time. (Ross, 1997) The calculations can be modified to account for a random loan period, but this is not done here. Table 9 shows the calculations for all items using equations (18) and (19). Table 10 shows the comparison between the values computed in table 9 and the MNUDDALT and SNUDDALT values computed in table 8. Although there are certainly differences in the values, they are relatively close enough for the purposes of generating an upper bound for this study. Note that the calculations using equations (18) and (19) use only simple summary statistics from the demand process.

Item #	Mean Time Between Loans	Standard Deviation of Time Between Loans	Average Loan Time in days	Mean Demand Size	Standard Deviation of Demand Size	Computed Mean Number of Units Demanded During Constant Loan Time	Computed Standard Deviation of Units Demanded During Constant Loan Time
1	36.2	27.24	41	3.09	4.7	3.50	5.58
2	265.5	91.21	40	5.33	3.05	0.80	1.38
3	43.57	43.57	46	1.25	0.53	1.32	1.40
4	25.78	27.05	42	3.88	2.19	6.32	5.90
5	16.3	14.76	45	4.08	1.63	11.26	6.71
6	14.91	15.43	43	3.96	2.54	11.42	8.19
7	8.3	9.1	43	3.80	2.56	19.70	11.14
8	49.81	47.68	34	12.35	8.45	8.43	12.01
9	73.06	67.02	35	8.87	6.65	4.25	7.27
10	33.21	34.56	36	12.08	8.43	13.10	15.76
11	11.54	12.68	46	5.94	3.21	23.67	14.52
12	10.43	8.34	47	23.27	14.67	104.87	50.30
13	274	134.67	38	2.45	3.45	0.34	1.36
14	14.61	18.91	47	15.68	10.34	50.43	40.85
15	40.56	36.78	34	5.80	3.12	4.86	5.60
16	23.32	27.65	39	2.97	4.56	4.97	7.45
17	73.07	58.93	45	3.95	2.12	2.43	3.00
18	121.67	85.63	44	2.46	1.23	0.89	1.28
19	22.83	21.89	40	10.08	13.69	17.66	22.18
20	35.35	33.68	49	5.36	3.27	7.43	7.14
21	21.08	23.56	32	15.65	11.83	23.76	26.02
22	43.84	39.15	36	3.62	5.28	2.97	5.61
23	99.64	85.95	38	0.55	1.29	0.21	0.85
24	19.23	22.43	46	3.11	3.72	7.45	8.04
25	84.31	79.4	41	8.88	4.71	4.32	6.70
26	23.32	23.67	40	15.60	9.26	26.75	24.02
27	52.14	55.43	46	3.00	4.71	2.65	5.34
28	84.31	81.33	42	1.39	0.93	0.69	1.15
29	60.83	46.84	38	11.03	5.84	6.89	8.15
30	35.35	35.89	45	13.71	15.67	17.45	23.65
31	9.61	11.12	44	3.76	4.55	17.23	13.48
32	29.62	32.45	47	3.84	3.24	6.10	6.69
33	28.08	25.67	38	10.76	4.59	14.56	12.63
34	23.83	24.57	41	3.56	2.12	6.13	5.56
35	10.74	11.56	41	4.13	1.59	15.76	9.22

Table 9: Alternative Method Results For Computing Mean and Standard Deviation of Number of Units Demanded During an Average Loan Time

Item #	Mean Number of Units Demanded During Constant Loan Time	Computed Mean Number of Units Demanded During Constant Loan Time	Standard Deviation of Units Demanded During Constant Loan Time	Computed Standard Deviation of Units Demanded During Constant Loan Time
1	1.89	3.50	2.75	5.58
2	0.33	0.80	1.13	1.38
3	1.29	1.32	1.16	1.40
4	8.34	6.32	7.98	5.90
5	15.5	11.26	18.5	6.71
6	10.56	11.42	7.67	8.19
7	16	19.70	7.86	11.14
8	7.67	8.43	10.62	12.01
9	3.78	4.25	3.42	7.27
10	11.33	13.10	9.55	15.76
11	24.67	23.67	16.64	14.52
12	114.11	104.87	58.15	50.30
13	0.22	0.34	0.87	1.36
14	52.56	50.43	40.73	40.85
15	5.11	4.86	5.08	5.60
16	4.44	4.97	3.51	7.45
17	2.22	2.43	3.6	3.00
18	0.78	0.89	1.26	1.28
19	16.44	17.66	12.45	22.18
20	6.44	7.43	5.59	7.14
21	22.56	23.76	13.29	26.02
22	2.67	2.97	4.21	5.61
23	0.11	0.21	0.33	0.85
24	7.22	7.45	4.95	8.04
25	4.11	4.32	4.14	6.70
26	24.56	26.75	11.35	24.02
27	2.11	2.65	4.86	5.34
28	0.56	0.69	1.13	1.15
29	6.22	6.89	9.97	8.15
30	16.11	17.45	19	23.65
31	15.67	17.23	8.64	13.48
32	5.22	6.10	4.12	6.69
33	12.78	14.56	15.38	12.63
34	4.78	6.13	3.97	5.56
35	15.44	15.76	8.2	9.22

Table 10: Comparison between the two methods discussed

APPENDIX J. NUMERICAL EXAMPLE DEMONSTRATING COMPUTATION OF SIMULATED SERVICE LEVELS

The following example demonstrates the methodology applied in this thesis for the computation of simulated service levels as individual units of inventory are added to each item. Table 11 represents the original stock level, demand and loan time data for Item A over a 15-day period.

Item: A Initial Stock Level: **10** Service Level Achieved: **80%**

Date	Quantity Returned	Quantity on Hand	Quantity Requested	Requested Loan Time in Days	Quantity Issued
95001	0	10	7	8	7
95002	0	3	0	0	0
95003	0	3	3	11	3
95004	0	0	2	3	0
95005	0	0	0	0	0
95006	0	0	0	0	0
95007	0	0	0	0	0
95008	0	0	2	9	0
95009	7	7	0	0	0
95010	0	7	6	7	6
95011	0	1	0	0	0
95012	0	1	2	4	1
95013	0	0	0	0	0
95014	3	3	0	0	0
95015	0	3	3	3	3
Totals			25		20

Table 11: Service level based on original data

Tables 12-14 show the simulated service levels achieved as one, two, and three units of inventory are added to the original stock level; all demand quantities, and loan times remain constant.

Item: A Initial Stock Level: 11 Simulated Service Level Achieved: 88%

Date	Quantity Returned	Quantity on Hand	Quantity Requested	Requested Loan Time in Days	Quantity Issued
95001	0	11	7	8	7
95002	0	4	0	0	0
95003	0	4	3	11	3
95004	0	1	2	3	1
95005	0	0	0	0	0
95006	0	0	0	0	0
95007	1	1	0	0	0
95008	0	1	2	9	1
95009	7	7	0	0	0
95010	0	7	6	7	6
95011	0	1	0	0	0
95012	0	1	2	4	1
95013	0	0	0	0	0
95014	3	3	0	0	0
95015	0	3	3	3	3
Totals			25		22

Table 12: Simulated service level based on adding one unit to stock

Item: A Initial Stock Level: 12 Simulated service Level Achieved: 96%

Date	Quantity Returned	Quantity on Hand	Quantity Requested	Requested Loan Time in Days	Quantity Issued
95001	0	12	7	8	7
95002	0	5	0	0	0
95003	0	5	3	11	3
95004	0	2	2	3	2
95005	0	0	0	0	0
95006	0	0	0	0	0
95007	2	2	0	0	0
95008	0	2	2	9	2
95009	7	7	0	0	0
95010	0	7	6	7	6
95011	0	1	0	0	0
95012	0	1	2	4	1
95013	0	0	0	0	0
95014	3	3	0	0	0
95015	0	3	3	4	3
Totals			25		24

Table 13: Simulated service level based on adding two units to stock

Item: **A** Initial Stock Level: **13** Simulated Service Level Achieved: **100%**

Date	Quantity Returned	Quantity on Hand	Quantity Requested	Requested Loan Time in Days	Quantity Issued
95001	0	13	7	8	7
95002	0	6	0	0	0
95003	0	6	3	11	3
95004	0	3	2	3	2
95005	0	1	0	0	0
95006	0	1	0	0	0
95007	2	3	0	0	0
95008	0	3	2	9	2
95009	7	8	0	0	0
95010	0	8	6	7	6
95011	0	2	0	0	0
95012	0	2	2	4	2
95013	0	0	0	0	0
95014	3	3	0	0	0
95015	0	3	3	5	3
Totals			25		25

Table 14: Simulated service level based on adding three units to stock

This example illustrates a key point in the methodology used, the simulated service level achieved based on making simulated changes to the initial stock level of any item is strongly influenced by the specifics of the historical demand data of that item. This is again a characteristic on this particular set of historical data, as well as a characteristic of a revolving inventory system. Also, notice that even though the original shortfall was five units, only three additional units had to be added to achieve a 100% service level for the historical demand. The results could be different for other demand streams. Again this is a characteristic of a revolving inventory system.

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APPENDIX K. EXAMPLE OF MISSION USEFULNESS SURVEY

Joint Operating Stocks Assessment Survey

The purpose of this survey is to establish an essentiality rank ordering of Special Operations Forces unique items maintained in the Joint Operating Stocks in Lexington KY. This ordering will ensure we allocate our limited dollars to maintaining the most critical levels of stock to support anticipated missions.

Please rank the items on the attached survey based on the scale provided

The primary goal of this study is to aid in establishing the optimal JOS inventory levels to support the warfighters in anticipation of real missions, based on the fiscal constraints we deal with.

Here are some guidelines regarding the grading criteria used in this survey:

Always Used – The mission will not even be attempted without this item. There is virtually a zero chance of mission success without it.

Frequently Used – Although not essential to mission success, the probability of mission success is impacted by not having this equipment.

Occasionally Used – Not essential to mission success, but it does provide an increased probability of mission success. Unlikely that a mission will be canceled for lack of this equipment.

Seldom Used – Probably would not take this item on any current mission even if it was available, but it can provide some usefulness, either as a substitute or as a training aid.

Very Seldom Used – Can't think of any mission this item might apply to right now, and don't normally use it as a substitute or in training. Equipment that is routinely evaluated in this category will be eliminated from the JOS inventory.

Place an X in the category that most accurately describes the essentiality of the item based on anticipated real world mission scenarios. If no category is marked, this will be interpreted as meaning the item is never used, nor is expected to ever be used.

Place an X in the category that most accurately describes the essentiality of the item based anticipated real world mission scenarios.

	Item	Always Used	Frequently Used	Occasionally Used	Seldom Used	Very Rarely Used
Communications Equipment	Antenna, Hatchmount,(C-130) SATCOM					
	Antenna, Hatchmount, (C-141) SATCOM					
	Antenna, SATCOM DMSE-109-1					
	Antenna, SATCOM UHF-6.5/7 DB					
	Improved Lightweight Satellite Antenna (ILSA)					
	Helmet, Padded (G022-4602-05)					
	Radio Set, AN/PRC-113					
	Radio Set, Portable SABER I, Motorola					
	Radio Set, Portable SABER II					
	Charger, Battery Multi/Single SABER					
	Radio Set, SATCOM AN/PSC-7					
	Sunburst Processor, AN/CSZ-1A					
	Inmarsat-B Transportable Earth Station					
	Advanced Data Controller					
	Secure Fax MFAX-5000					
	STU III Phones					
Optics/Night Vision	Aiming Light, Infrared W/Beam (TD-110)					
	Night Weapons Sight, Litton Ranger M995					
	Compact Binoculars					
	Illuminator, Laser Head (IL-7)					
	IR Laser, Long Range Pointer LPL-30					
	Lens, Zoom 100-500 MM, Vivitar Series 1					
	Night Vision Goggles, AN/PVS-7B					
	Scope, Rifle, Blits					
	Thermal Imaging Sight MAG 600					
	Stinger Night Sight AN/PAS-18					
	Thermal Imager AN/PAS-19					
	Thermal Imager AN/PAS-20					
	Infrared Observation Set (MELIOS)					
	Night Laser Ranger and Compass Binoculars N/CROS MKII					
	Scope, Spotting W/Case & Tripod (Bushnell)					
	Sight, Optical, Simrad (KN200F & KN250F)					
	Laser Marker, AN/PEQ-1 (SOFLAM)					
	Transponder Set, AN/PPN-19(V)2 (Radar Marking Beacon)					
	Pointer, Ground Commander's IR (GCP-1B)					
	Pointer, Ground Commander's IR (GCP-2A)					
	Surveillance System, Tactical					
	Binoculars, Night Vision AN/PVS-15 (BNVS)					
	Digital Imaging Set, Base Station					
	Digital Imaging Set, Outstation					

	Item	Always Used	Frequently Used	Occasionally Used	Seldom Used	Very Rarely Used
Weapons	Rifle, Sniper, 50 Cal. Barrett					
	Submachine Gun, MP5A3/A5					
	Submachine Gun, MP5SD3					
	Rifle, Sniper SR-25					
	Rifle, Sniper Remington 700 300 WIN MAG					
Field Support	Filtration System, Water MDL 150/M6000 (360 GPH)					
	Filtration System, Water MDL SP2-AP (Backpack – 60 GPH)					
	Desalination Unit, Water LS/RO-1500 (102 GPH)					
	Generator Set, Diesel Engine					
	Generator Set, 30KW					
	Generator Set, 60KW					
	Power Distribution Panel, 30KW					
	Power Distribution Panel, 60KW					
	Environmental Control Unit (ECU-51)					
	Environmental Control Unit (ECU) (MDL AH-54)					
	Tent, Temper					
	Lights, Portable Gas Powered					
	Floodlight Set, Electric (MDL FS 100)					
	Pressure Washer					
	Small Shower Unit					
Other	Boat, Inflatable F-470 ZODIAC					
	Cache Locating Device					
	Fax Machine, Portable (MFAX-5000)					
	Nav Set Magellan GPS 1000 M5 MDL21002					
	Navigation Set, Satellite Signals AN/PSN-11(v)1 (PLGR)					
	Vest, Protective, Zinner W/Level III Inserts					
	Vest, Protective, Ranger W/Inserts Front Only					
	Vest, Protective, Ranger W/Inserts Front & Back					
	Blanket, Breacher W/Case					
	Blanket, Breacher Black 72 x 32, 30 Ply					
	Diver Navigation Board TAC-100					

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