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AN EMPIRICAL INVESTIGATION OF
THE EFFECTS OF INVENTORY STOCKAGE
MODELS FOR RECOVERABLE ITEMS ON
WEAPON SYSTEM AVAILABILITY

James A. Duke, 1st Lt., USAF
Kenneth W. Elmore, 1st Lt., USAF

LSSR 14-81

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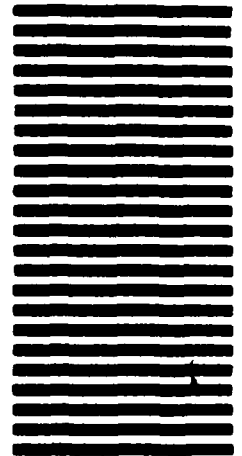
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The current U. S. Air Force method of requirements determination and distribution is referred to in this thesis as the conventional method. The conventional method is a non-optimizing technique which neither minimizes backorders nor maximizes availability. METRIC (Multi-Echelon Technique for Recoverable Item Control) is being implemented to replace the conventional method. The advantage of METRIC is that it minimizes backorders. After developing a method of ascertaining the availability produced by a logistics system, this study compares the availability results of both METRIC and the conventional model. This study uses for a data base a small weapon system employed at only one base. The results show that METRIC is superior to the conventional model not only in terms of backorders, but more importantly, in terms of availability.

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AN EMPIRICAL INVESTIGATION OF THE EFFECTS OF
INVENTORY STOCKAGE MODELS FOR RECOVERABLE ITEMS
ON WEAPON SYSTEM AVAILABILITY

A Thesis

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Logistics Management

By

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June 1981

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This thesis, written by

First Lieutenant James A. Duke

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has been accepted by the undersigned on behalf of the
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fulfillment of the requirements for the degree of

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COMMITTEE CHAIRMAN

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TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS	iii
LIST OF TABLES.	vii
LIST OF FIGURES	viii
 CHAPTER	
I. INTRODUCTION.	1
Background.	1
Problem Statement	5
Research Objectives	5
Research Questions.	6
Scope	6
II. LITERATURE REVIEW	7
Introduction.	7
USAF Inventory Management	8
Repair Cycle Concept.	8
Cannibalization	11
System Performance Indicators	11
Expected Backorders	13
Fill Rates.	14
Operational Rate.	14
Expected NORS Aircraft Assuming Full Cannibalization.	15
Approximate Expected NORS Aircraft With No Cannibalization	16

CHAPTER	Page
Exact Availability With No Cannibalization	17
Stockage Models	19
Conventional Model.	19
METRIC.	21
Air Force Implementation of METRIC.	26
Related Studies	27
MOD-METRIC.	28
DYNA-METRIC	29
METRIC-LMI.	32
Dawson's Study.	32
Demmy's Study	35
Summary	35
III. METHODOLOGY	37
Overview.	37
Data Base	37
Candidate Items	38
Item Usage Data	40
Data Collection Problems.	41
Heuristic Availability Algorithms	42
Testing, Validation, and Verification	44
Outline of Research Procedure	45
IV. RESULTS	48
Introduction.	48
System Performance With Conventional Budget Constraint	48

CHAPTER	Page
Analysis.	50
System Performance With Budgetary Constraint 150% of the Conventional Budget	51
Analysis.	51
Sensitivity Analysis.	54
Research Questions.	57
V. SUMMARY AND CONCLUSIONS	59
Summary of the Research	59
Conclusions of the Research Effort.	60
Managerial Implications	61
Significant Methodological Issues	62
Suggested Areas of Further Research	63
Final Comments.	64
APPENDIX A.	65
SELECTED BIBLIOGRAPHY	83
A. REFERENCES CITED.	84
B. RELATED SOURCES	85

LIST OF TABLES

Table	Page
1. Selected Assets	39
2. Comparison of Inventory System Performance With Conventional Budget Constraints.	49
3. Comparison of Stockage Postures With the Conventional Budget Constraint.	52
4. Comparison of Inventory System Performance With a Budget Constraint of 150% of the Conventional Budget	53

LIST OF FIGURES

Figure	Page
1. Two Echelon Inventory System	10
2. Research Procedure	47
3. Sensitivity Analysis	55
4. System Availability.	56

CHAPTER I

INTRODUCTION

Background

The Logistics Long-Range Planning Guide (LLPG) was recently completed drawing on information provided by the USAF Global Assessment, an Air Force sponsored long-range planning task force, a study by the Air Force Logistics Management Center and a long-range planning seminar attended by representatives of all major commands. Four logistics objectives were expressed in the LLPG (16:1), two of which apply directly to the theme of this research:

(1) develop a means to better identify and assess logistics requirements and capability, especially as these relate to execution of U.S. contingency plans,

and

(2) effectively manage or influence the management of scarce logistics resources to maintain Air Force combat capability.

Capability implies aircraft availability. This availability is directly affected by how assets are bought and distributed to the operational user. The purchase and distribution of assets is the domain of the field of logistics. The logistics function within the Air Force is

now so large and sophisticated that, as noted in the
LLPG (16:1):

Logistics manages a significant portion of all Air Force resources. . . . 43 percent of the total Air Force military personnel, 50 percent of the enlisted force, and 25 percent of the current Air Force budget is devoted to performing the logistics mission in 1980.

As this growing awareness of the importance of logistics suggests:

. . . greater emphasis must be placed on assessing and identifying logistics support capability in order to appraise realistically what can or can not be accomplished with available assets. This is particularly important to the budgetary process. Spares have not been adequately funded in recent Air Force Budgets. The present shortfall between peacetime procurement and the level of spares required to fully support a wartime effort can be traced to a poorly articulated logistics position during the POM (Program Objectives Memorandum) preparation cycle. The problem has been due in part to an inadequate requirements computation process, leading to a poor assessment of the long-range effects of near term budgetary decisions as they pertain to operational readiness and sustainability [16:2-3].

The strategy outlined to help overcome the stockage of spares problem and to provide adequate weapon system availability is expressed as follows: "develop the means to assess and relate logistics needs and budgetary decisions to operational capability [16:3]." The LLPG further states that there will probably be a limited number of spares to work with and that it is essential that the logistics manager know the requirement, condition, availability, and

location of the scarce assets at all times (16:3).

The scarcity of assets was strongly felt at Langley AFB where an Operational Readiness Inspection (ORI) was terminated, due basically to the inability to generate aircraft within the standard time frames due primarily to lack of spares (13:4).

For the Air Force, the stockage and management of spares is essential to maintain a state of readiness that will deter aggression and promote peace through our national defense policy. This readiness can only be maintained if the equipment and spares are available. The requirements computation which determines the inventory levels to be maintained does not adequately promote weapon systems availability.

The purpose of this research is to explore the various stockage models in an effort to relate them to availability. The conventional model presently utilized by USAF for the requirements computation is based upon the maintenance of an average level of stock. It is a satisficing model in that it merely sets inventory levels to meet minimum requirements. The effectiveness of this model is measured in terms of fill rate and Mission Capability (MICAP) rate, provided by the Monthly Base Supply Management Report (M-32). These measures do not reveal to management how available the weapon system is to perform its designated mission. A new stockage model has recently been imple-

mented in the USAF requirements determination. The Multi-Echelon Technique for Recoverable Item Control (METRIC) is designed to minimize expected backorders associated with stockage level of any individual asset. The only measurement of this model is that of expected backorders. Minimizing expected backorders however, does not necessarily mean providing the maximum weapon system availability at the least cost. Thus, if the conventional and METRIC models cannot provide maximum availability, perhaps an alternative model should be considered.

Seventy-two percent of the people surveyed in a recent Gallup Poll indicated that they felt that money spent for defense was not being utilized efficiently (9:48-50). This came at a time when expenditures for spare parts alone was \$1.7 billion for fiscal year 1981 with an anticipated rise to \$2.5 billion for 1982 (18:51-67). The public conviction of defense inefficiency indicated in the Gallup Poll has contributed to a growing political interest in closely scrutinizing defense spending. Thus, the budgetary limitation will have an effect on the availability of weapon systems.

Of the total money spent on spare parts, approximately 95% will be spent on repair cycle assets. A repair cycle asset is normally characterized by high cost and the capability of being repaired and reused (15:1). The purchase price of repair cycle assets is so disproportionately high

compared to other supply items that although only 5% of the line items to be stocked are reparable, this represents 95% of the total dollar value of a base's inventory (14:5). Since the assets are so expensive, the method of allocating them must be such that with limited funds, maximum availability is obtained.

Problem Statement

The conventional model provides a target service level of asset stockage. It is a function of the total number of assets required for normal demands and those experienced during the resupply time. It is not known what level of availability the model can provide.

The METRIC algorithm provides a cost effective minimization of expected backorders. It is not known what level of availability this provides. Other models have also been developed for the purchase of assets. It is not known what level of availability they can provide.

Research Objectives

The objectives of this research are: first, to analyze the existing method (conventional model) of determining an inventory position for repair cycle assets using a small, yet select, data base; second, utilizing the same data base, analyze METRIC; and third, develop alternative heuristic models and analyze each one using the same data

base. In all of these objectives the analysis will be undertaken to determine what the weapon system backorder position is and what level of availability is provided.

Research Questions

(1) What level of availability can the conventional model provide?

(2) Since METRIC is currently being implemented by AFLC for requirements determination and given that it does minimize expected backorders, what level of availability can it provide?

(3) How do the heuristic models compare to METRIC and the conventional model?

Scope

This research will examine the conventional model, METRIC and three alternative heuristic models. The data base will be taken from a small weapon system employed at a single base. The use of a single-base system greatly simplifies the required computations and tends to eliminate possible errors. While the conclusions drawn may be applicable to all DOD systems, the results will focus only on the one weapon system used.

CHAPTER II

LITERATURE REVIEW

Introduction

After stating a research objective, a review of pertinent works is appropriate. It must be realized that inventory models are concerned with both consumable and repair cycle assets and that the requirements computation is not the same for each. Thus, a discussion of consumables will be followed by a discussion of repair cycle assets. The repair cycle concept is basic to any study of the levels computed for inventory requirements. Cannibalization -- the process of removing an asset from one end item and placing it on a similar end item -- also plays a role in achieved levels of weapon system availability. Performance measurements of the various models are indicators to management of how well an inventory system is supporting the operational mission. Expected backorders, fill rates, and system availability both with and without cannibalization are the performance measures of interest for this research. Expected weapon system availability estimates can be deduced from the expected fill rates of individual items. These concepts form the basis for the discussion of the logic and intent of the conventional and

METRIC models. A section concerning the Air Force implementation of METRIC will be followed by the related studies of MOD-METRIC, DYNA-METRIC, a Logistics Management Institute (LMI) model, and research performed by Dawson and by Demmy. These related studies will suggest a methodology for completion of the research. Although the term NORS (Not Operationally Ready - Supply) is outdated, a large portion of the literature utilizes it. Therefore, the term NORS will be used interchangeably with what is today known as Not Mission Capable - Supply (NMCS).

USAF Inventory Management

Inventory procedures are designed to determine levels for consumable and repair cycle assets. Consumable requirements are determined based upon an Economic Order Quantity (EOQ). These are important assets in meeting the operational requirements. However, the focus of this research is on how inventory levels are established for repair cycle assets.

Repair Cycle Concept

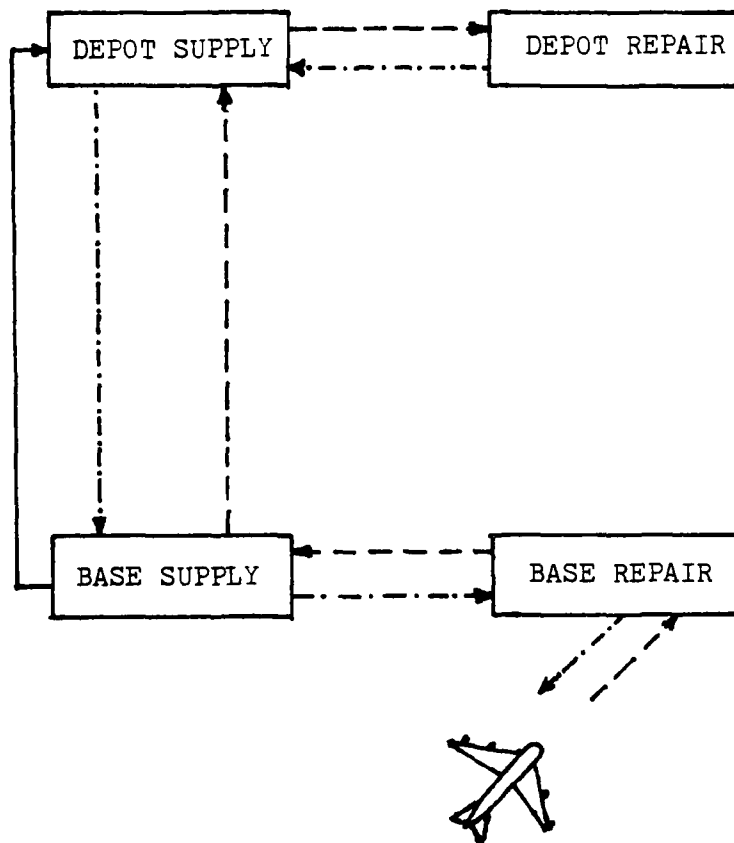
The repair cycle concept is based upon a two echelon system. Items that have failed are removed from the aircraft or end item and repaired at the base facility if possible. If a serviceable like item is available at the base, it is installed on the aircraft while the failed

item is being repaired. In this situation, once the item has been repaired, it becomes part of the base stock. If no like item is available, the item is returned to the aircraft after being repaired.

Frequently, the base is unable to repair the failed item. These incidents are known as Not-Repairable- This-Station (NRTS). NRTS items are returned to the depot for repair or condemnation. When this action is required, a demand is placed on the depot for a serviceable item. When the depot has the item in stock, it is sent to the base prior to the arrival of the failed item at the depot. If no item is in serviceable stock at the depot, the resupply is delayed until an asset returns from the depot repair facility.

Upon arrival at the depot, the unserviceable item from the base goes through the depot repair cycle and becomes a part of the depot stock. When the serviceable item is sent to the base from the depot, it is given to the maintenance facility for replacement on the aircraft or is returned to base stock. This completes the cycle for the reparable asset. See Figure 1 for a pictorial representation of this two echelon environment.

The fundamental decision in the two echelon environment is the determination of the total number of assets required to support the weapon system. The total requirement consists of those assets in stock at base supply, in



—————→ Requisition Flow
 -----→ Unserviceable Item Flow
 -.-.-.-.-→ New or Repaired Item Flow

Figure 1. Two Echelon Inventory System (4:5)

repair at the base, in repair at the depot, in stock at the depot, and those in the transportation network between the base and the depot.

Cannibalization

The concept of cannibalization plays an important role in the behavior of an inventory system since each aircraft can become a pool of usable assets which can be utilized to satisfy a backorder on another aircraft. Cannibalization is the process of removing an asset from one end item and successfully replacing it on another end item. In this way, shortages for two items, which might have grounded two aircraft, can be consolidated onto one aircraft. Thus, the implications of cannibalization are readily seen as an aid to increased aircraft availability.

System Performance Indicators

All Department of Defense systems, whether weapon systems or otherwise, have their performance measured by comparison with a standard or to a similar system. Performance measures associated with the stockage levels within the Air Force supply system are expected backorders, fill rate, operationally ready rate, and a NORS/NMCS rate. Also discussed here is an availability rate based upon a method developed by the Logistics Management Institute and one developed by Dr. Jon Hobbs (8) of Wright State

University.

There is a certain amount of ambiguity in the term "NORS". If an asset is missing from an aircraft and as a result the aircraft is grounded then the asset is referred to as an item NORS and the aircraft itself is referred to as NORS. It is important to note that there may be more than one item NORS for every NORS aircraft. Thus, there may be two, three or more items NORS but only one corresponding aircraft NORS.

Several assumptions must be made to monitor the behavior of individual items. The following is a list of those assumptions.

(1) One-for-one requisitioning means that for every reparable asset sent by the base to the depot, there is a corresponding requisition from supply to the depot.

(2) Backordering of unsatisfied demands means that when an asset is demanded from supply and the item is not in stock, it will be backordered.

(3) Stationarity of the variables means that there is no trend, seasonality or cyclical influence in the variables such as demand and order and ship time. There is no learning curve phenomenon in the repair times at either depot or base.

(4) Independence of resupply time and demand means that the demand for an asset and the time it takes to obtain it from the depot or base maintenance facility will

vary in a statistically independent manner.

(5) The number of demands during a given time interval is a Poisson distributed random variable.

(6) No batching for repair means that each asset in the system for repair will enter the repair queue immediately upon arrival at the repair facility. Each asset will be repaired individually.

(7) No delay for indenture items means that all bits and pieces are immediately available for the repair of the asset.

Expected Backorders

A backorder occurs when the number of demands exceeds the quantity of available serviceable assets for any item. Thus, a backorder B can be expressed as:

$$B = d - s \quad (1)$$

where d = demand, and s = quantity stocked. The average or expected backorders (1:10) can be stated as:

$$E(B) = \sum_{d=s+1}^{\infty} (d-s) p(d|\lambda\tau) \quad (2)$$

where λ = daily demand rate

τ = average resupply time

and $p(d|\lambda\tau) = p(d=x) = \frac{e^{-\lambda\tau} \lambda\tau^x}{x!}$.

Fill Rates

A fill rate, stated in simple terms, is the number of times an item is available from serviceable stock when it is demanded. As stated by Brooks, Gillen, and Lu, it is the proportion of demands for item i which can be filled from on-hand assets and is equal to the proportion of time that on-hand assets are positive. The on-hand assets will be positive only if the number of due-ins is less than the level. The fill rate for any given item (1:11) can be found as follows:

$$FR_i = \sum_{d=0}^{s_i} p(d|\lambda\tau_i) \quad (3)$$

The Air Force measurement of fill rates is closely monitored by use of the Monthly Base Supply Management Report (M-32).

Operational Rate

An operational aircraft is one that can perform all of its missions. Assumptions of the operational rate are that demand and resupply times of the items are independent and that full cannibalization will be performed. The

operational rate is a function of the fill rates and is expressed as follows:

$$\text{Operational Rate} = \prod_{i=1}^n \text{FR}_i \quad (4)$$

where n is the number of items. Note that this is a theoretical rate and is for the whole fleet. Since the fill rate depends upon the probability of demand, it can be shown that the operational rate with zero cannibalization has the form of:

$$\text{OR Rate With Zero Cann.} = \prod_{i=1}^n \sum_{d=0}^{s_i} p(d|\lambda\tau_i) \quad (5)$$

If cannibalization is to be considered then the equation takes this form (1:12-13):

$$\text{OR Rate With Cann.} = \prod_{i=1}^n \sum_{d=0}^{s_i + [Q_i \cdot J]} p(d|\lambda\tau_i) \quad (6)$$

where s_i = stockage of item i ,

Q_i = quantity available on each aircraft,

J = number of aircraft cannibalized.

Expected NORS Aircraft Assuming Full Cannibalization

Item essentiality and consolidation of parts shortages

are necessary assumptions to arrive at this figure. An aircraft can only be NORS if demand exceeds the serviceable stockage level. The probability of an aircraft being NORS at any given time depends upon the cannibalization policy. Thus, the probability that zero aircraft are not available to perform their mission is simply the operational rate with zero cannibalization. The probability that one or fewer aircraft are not available to perform their mission is the operational rate with one cannibalization minus the operational rate with zero cannibalization. A general equation to determine the expected number of aircraft not available is:

$$E(\text{Not Avail}) = \sum_{i=0}^A ip(i) \quad (7)$$

where A = the number of aircraft in the fleet and p(i) is the exact probability that i aircraft are not available. This rate does provide a direct estimate to management on what the defensive or offensive posture of the force may be capable of accomplishing.

Approximate Expected NORS Aircraft With No Cannibalization

A model developed by the Logistics Management Institute (LMI) provided a measure of aircraft availability. An assumption of this model is that cannibalization would not

be performed. It could be shown that the probability of any aircraft being available can be expressed as:

$$P(\text{Available}) = \prod_{i=1}^n \left[1 - \frac{E(B_i)}{A \cdot Q_i} \right]^{Q_i} \quad (8)$$

where $E(B_i)$ = expected backorders for item i ,

A = number of aircraft,

Q_i = number of units of item i on each aircraft,

n = number of items.

From this expression it can be determined what the expected number of unavailable aircraft would be.

$$\text{Expected Acft Not Avail} = A - [p(\text{Avail}) \cdot A] \quad (9)$$

Exact Availability With No Cannibalization

A model developed by Jon Hobbs (8) is similar to that of the approximate availability from LMI. The same assumption is made that cannibalization will not be performed. This model is expressed as:

$$p(\text{Avail}) = \prod_{i=1}^n \left[\sum_{d=0}^{s_i} p(d | \lambda \tau_i) + \sum_{d=s_i+1}^{s_i+(Q_i A)} \left(1 - \frac{d-s_i}{A Q_i} \right)^{Q_i} p(d | \lambda \tau_i) \right] \quad (10)$$

where d = demand for the item,

s_i = stock for the item,

Q_i = quantity per application,

A = number of aircraft,

$\lambda\tau_i$ = replenishment time $\cdot$ daily demand rate,

n = number of items.

From this it can be shown that the expected number of unavailable aircraft is:

$$\text{Expected Acft Not Avail} = A - \left[p(\text{Avail}) \cdot A \right] \quad (11)$$

The difference between the two models is this: where the approximate model is based upon an average, or expected backorder figure, the exact model is based upon the actual backorder figure.

Three cannibalization models are considered to provide management a range of availability data upon which to base decisions. Each model provides a different estimate of availability. Since the cannibalization decision is a management option, and since cannibalization can be a time-consuming activity, availability estimates should be made with and without the assumption of cannibalization to show the range of availability which can be obtained.

The approximate model is more widely known and is easier for computational purposes. It is a reasonable approximation in situations where the fleet size is rela-

tively large, but leads to significant under-estimation of availability if the fleet size is small.

Stockage Models

The Air Force is currently using what will be called here the conventional model to determine the levels of items required for support of the weapon systems. The Air Force is also implementing a new procedure called METRIC. The features of these models will be examined in detail.

Conventional Model

The conventional model is not intended to minimize or maximize any measure of supply performance. Three features of the model are that it computes a level for the base, a safety level, and a level for the depot. The base quantity is determined as follows:

$$BQ = \left[\left[(1 - PBR) \cdot OST \right] + (PBR \cdot RCT) \right] \cdot DDR \quad (12)$$

where PBR = percent of base repair,

OST = order and ship time

RCT = repair cycle time at the base,

DDR = daily demand rate.

This value is then utilized to compute the safety level.

$$SL = \sqrt{3 \cdot BQ} \quad (13)$$

A rounding value is then added, depending upon the unit cost of the item. Thus, if the unit cost is less than \$750.00, a value of .9 is added and BQ is rounded down to the integer value. If the unit cost is greater than \$750.00, a value of .5 is added and BQ is rounded down. Taking the preceding equations, the total base quantity can be expressed as:

$$\text{Total Base Quantity} = \text{BQ} + \sqrt{3 \cdot \text{BQ}} \quad (14)$$

The depot quantity is that required for support of all the bases while depot repair and those items in the transportation mode complete the repair cycle. The depot quantity is calculated as follows:

$$\text{DQ} = \left[(1 - \text{PBR}) \cdot \text{DDR} \cdot (\text{DRT} + \text{RETRO} + 30) \right] + .5 \quad (15)$$

where DRT = depot repair time,

RETRO = a standard shipping time based upon the item's priority,

30 = a constant factor which acts as the safety level,

.5 = a constant to allow for rounding down to the integer value.

Assumptions of this model are that the demand is stationary and that no trend or seasonality exists. A feature of the

model is that it does not consider any cost associated with the item. In other words, purchase cost, repair cost, shipping cost, and holding costs are not inputs to the model except in the rounding algorithm (17:p.11-13).

This model neither minimizes backorders nor maximizes availability. It does provide a service level of support. The service level is expressed as a percentage, such as 84%. For reparable assets, an 84% service level means that the model intends to provide an 84% fill rate for each item.

METRIC

The Multi-Echelon Technique for Recoverable Item Control (METRIC) employs a systems approach to providing placement of assets. It looks at the entire weapon system to provide a combination of system effectiveness and system cost analysis. The purpose of METRIC is to optimize system performance for specified levels of system investments where system performance is measured in terms of total backorders. The model is designed for one depot to provide support to several bases (15:1).

The intent of this model is threefold: to determine optimal base and depot stock levels for each item, considering constraints on investment and performance; to optimally redistribute fixed levels of stock between the

depot and bases; and to assess performance and investment cost of the system for any allocation of stock between the depot and bases (15:2).

The features of this model may be summarized as follows:

(1) It can be operated as a single-echelon base stockage model.

(2) A combination of past data and future requirements are used to anticipate build-ups or phase outs.

(3) It provides for a smooth transition from initial support planning to follow-on provisioning.

(4) It provides for evaluation of different maintenance policies or pipeline times.

(5) It provides management the capability to examine the effect of varying degrees of support, depending on the mission importance of different weapon systems (15:2-3).

The objective of this model is to minimize the sum of backorders on all recoverable items at all bases pertinent to a specific weapon system for a given dollar investment in inventory assets (15:6). To define the backorder objective, take a fixed period of time and add together the number of days on which any unit of any item at any base is backordered. Divide this number by the length of the period. The expected value of the statistic provides a number independent of the period length. This value is what the model attempts to minimize. The model sees a backorder as any point in time when a recoverable item is

missing from an aircraft (15:6).

The inputs to this model are:

λ_i = the demand rate for the item at base i,

n = number of bases utilizing the item,

M_i = repair cycle time (RCT) at base i,

M_d = depot repair time plus retrograde time,

S_i = order and shipping time (OST) of the item at
base i,

P_i = percent of repair capability at base i,

$\bar{P}_i$ = percent of items not being repaired at the base,

Q = quantity authorized for stock,

B_i = backorders at the i^{th} base.

λ_i is the mean of a Poisson distributed random variable.

$$\tau_i = M_i P_i + S_i \bar{P}_i \quad (16)$$

is the average time to replace a repair cycle item.

The expected number of backorders at the i^{th} base is determined by:

$$E(B_i) = \sum_{x=Q_i+1}^{\infty} (x - Q_i) P(x|\lambda_i \tau_i) \quad (17)$$

At this point, the model has not considered the fact that the depot may not have the item in stock. The effect would be to delay resupply of the item. This is a valid

part of the model and must be evaluated. $\lambda_i \tau_i$ is thus re-defined as follows:

$$\lambda_i \tau_i = \lambda_i (M_i P_i + [S_i + D(?)] \bar{P}_i) \quad (18)$$

where $D(?)$ is the expected delay for an item at the depot which will be defined.

The depot demand rate is expressed as:

$$\lambda_d = \sum_{i=1}^n \lambda_i \bar{P}_i \quad (19)$$

The mean of a random variable, depot demands during re-supply time, is: $\lambda_d \tau_d$, or equivalently, $\lambda_d M_d$.

At any point in time, it can be determined how many units are being delayed. This is expressed as:

$$E(B_d) = \sum_{d=Q_d+1}^{\infty} (d - Q_d) P(d | \lambda_d M_d) \quad (20)$$

where Q_d is the quantity authorized at the depot.

The model, however, is interested in average delay per demand. To obtain this, division by the expected number of demands over that time period is required. $D(?)$ can now be defined.

$$D(?) = D(Q_d) = E(B_d)/\lambda_d \quad (21)$$

which provides the average delay per requisition as a function of the quantity of stock authorized at the depot. The expected backorders at base i , $E(B_i)$, (Equation 17) thus becomes a function of Q_i and Q_d .

The total number of assets in the system, Q_T , can now be expressed as:

$$Q_T = Q_d + \sum_{i=1}^n Q_i \quad (22)$$

The METRIC model computes $E(B)$ for any distribution of Q_T assets. Then, using marginal analysis and the $E(B)$ values just computed, it will provide the optimal distribution of the Q_T assets with an objective of minimizing:

$$\text{Min } \sum_{i=1}^n E(B_i) \quad (23)$$

Given m items that cost C_j dollars each, a LaGrangian procedure is used to optimally procure the m items subject to a constraint equal to the budget. Its objective is:

$$\text{Min } \sum_{j=1}^m \sum_{i=1}^n E(B_{ij}) \quad (24)$$

subject to:

$$\sum_{j=1}^m \left[\sum_{i=1}^n Q_{ij} + Q_{dj} \right] C_j \leq \text{Budget} \quad (25)$$

There are problems and assumptions with this model which suggest the need for an improved model. Some of these are:

- (1) The model works under steady-state conditions. That is, as previously mentioned, there is stationarity of the variables. The basic METRIC model does not deal with surges in demand.
- (2) It does not tell what the base availability is.
- (3) There is no consideration for cannibalization.
- (4) Lateral supply is not considered.
- (5) Each item is assumed to be equally essential.

Air Force Implementation of METRIC

Recently, the Air Force Logistics Command (AFLC) implemented a procedure which utilizes marginal analysis to determine stockage levels for repair cycle assets. The

intent of this procedure was to reduce base level backorders with no increase in stockage cost, reduce stockage cost without increasing base level backorders, or both. Simplifications necessary to implement the procurement procedure were that all users have the same demand rates, the same order and ship time, the same base repair cycle, and the same depot repair percent.

The basic algorithm for the marginal analysis is the same as described in METRIC. There are two phases to this procedure. Phase I determines the total stockage levels required and Phase II determines where these items should be stocked.

The probability of a backorder is the probability that demands during any time period will exceed the stockage levels plus due-ins minus due-outs. The cost of reducing backorders can be found by adding one more unit to the existing stockage level then dividing by the cost of that item (6:16).

AFLC has in fact implemented Phase I of this procedure. Phase II, the distribution algorithm, has not been implemented (12).

Related Studies

The Air Force utilizes the conventional and METRIC models for requirements determination. There is a wealth of related research on the subject of inventory require-

ments. The studies and models most pertinent to this thesis are: MOD-METRIC; DYNA-METRIC; METRIC-LMI; and two heuristic models, one of which was developed by Dawson and another by Demmy. As previously stated, the conventional model does not optimize any performance measurement. METRIC minimizes expected backorders. The features of alternative models will be discussed in this section.

MOD-METRIC

This model considers that there may be indenture items for repair of other reparable. In other words, a reparable asset may be a subassembly of another reparable asset. An assumption of the model is that there will only be two echelons. It recognizes the relationships between an assembly and its subassemblies and has as an objective the minimization of expected backorders, for the end item subject to a budgetary constraint. MOD-METRIC does not assume that each item is equally essential. A difference from METRIC also exists in how MOD-METRIC states the resupply time of any given item from the depot. For this model, average resupply time is T_i and is stated as (11:472):

$$T_i = r_i(R_i + \Delta_i) + (1 - r_i)(A_i + \delta(S_d)D) \quad (26)$$

where r_i = the probability a failure isolated to a given module will be repaired at base level,

R_i = average repair time at the base if modules are available,

Δ_i = expected delay in base repair time due to a backorder on the required module,

A_i = average order and ship time,

S_d = stock level at the depot,

D = average depot repair time

δ = depot delay time divided by depot repair time.

DYNA-METRIC

Unlike the conventional model and METRIC, DYNA-METRIC takes into consideration that the system may not be at a steady state. The problems faced are the same: the determination of how much spare stock to maintain and what level of performance can be achieved given a specified investment level (7:2).

This model addresses the feasibility of cannibalization to meet the parts requirement. It also can provide an indication of how severe a backorder can be. This is based on the number of aircraft and the number of sorties flown.

To provide for a non-steady state, the demand must be non-steady. The demand process is called a non-homogeneous Poisson process with an intensity function $m(t)$, $t \geq 0$ if:

- (1) The number of demands existing at time $t=0$ is zero,
- (2) The number of demands in disjoint time increments

are independent of each other.

- (3) The probability of more than one demand in an increment becomes infinitely small as the increment becomes small.
- (4) The probability of one demand in any increment is given by the intensity function $m(t)$ times the length of the increment as the increment gets small (7:5-6).

The expected number of systems not operational at a given time t with the assumption that only one component is on the system can be expressed as:

$$EN(t) = NA(t) \left[1 - \prod_{i=1}^N \left(1 - \frac{EB_i(t)}{NA(t)} \right) \right] \quad (27)$$

where $NA(t)$ is the number of major systems supported at time t (7:18).

If there is more than one unit on the system, then $EN(t)$ becomes:

$$EN(t) = NA(t) \left[1 - \prod_{i=1}^N \frac{\sum_{j=0}^{\infty} \binom{Q_i NA(t) - y}{Q_i} PB_i(y)}{\binom{Q_i NA(t)}{Q_i}} \right] \quad (28)$$

where Q_i is the quantity of item i per system and where

$PB_i(y)$ represents the probability of item i having y shortages at any time t .

$$PB_i(y) = \begin{cases} \sum_{K=0}^{S_i(t)} \frac{e^{-\lambda_i(t)} \lambda_i^K(t)}{K!} & \text{for } y = 0 \\ \frac{e^{-\lambda_i(t)} \lambda_i^{S_i(t)+y}(t)}{(S_i(t) + y)!} & \text{for } y > 0 \end{cases} \quad (29)$$

(7:19)

The expected number of systems not operational at any given point in time considering full cannibalization can now be expressed as:

$$EN_c(t) = \sum_{j=0}^{NA(t)-1} [1 - P(j)] \quad (30)$$

where $P(j)$ is the probability that the number of non-operational systems is less than or equal to j (7:20).

Any model has different aspects of potential areas of improvement. Some drawbacks of this model are: (1) the different service processes must be taken into consideration for the set of state equations since the Poisson properties are lost; and (2) the states of all components

sharing the same set of servers must be considered at one time (7:34).

METRIC-LMI

The Logistics Management Institute designed a program to be used in conjunction with the METRIC requirements determination system. The program can be used to compute expected backorder reductions for each additional spare unit. The METRIC-LMI model makes several assumptions. First, an aircraft will be NORS if it is missing one or more critical (NORS-causing) recoverable assets. Second, an aircraft cannot be NORS unless it is missing at least one of the above mentioned assets, and no spare is available. Third, failure of a critical item is independent of the failure of other components and is independent of the NORS/NOT NORS condition of the aircraft that it is installed on. Fourth, when there is more than one unit of an asset on any one aircraft, the failure of the assets are mutually independent (9:12). The major assumption in the model is that there is no cannibalization. All calculations were based on large fleets (such as 800 B-52's).

Dawson's Study

In 1977, Captain David Dawson explored the problems of supply requirements computation and its relationship to aircraft availability. The performance criterion used for

availability was NORS.

Using data from eight months of accumulated NORS data for the A-7D aircraft, Dawson developed a heuristic method for approaching the problem of availability. Rather than developing an over-all requirements computation system, the Dawson method selects candidate items for availability improvement. In the case of the A-7D, for example, only those items which historically had caused a NORS would be considered for improved requirements computation.

Recognizing that historical data might not be available or entirely accurate in every case, he developed a method for determining expected NORS. Then a method for determining the benefit for adding each additional item was developed. With a formula for expected NORS and for benefit, Dawson could evaluate hypothetical item investments by selecting first the item with the highest benefit per dollars spent.

Following this, he gave a rather involved explanation of the relationship between "aircraft" NORS and "supply" NORS. Any item on an aircraft which, if broken, would cause the aircraft to be grounded was referred to as a "supply" NORS. It is entirely possible that several items may fail during the same time period. Thus, there may be several "supply" NORS items for every NORS aircraft. Dawson concluded that, on the average, there are two supply NORS for every aircraft NORS.

He expressed the benefit/cost ratio as follows (4:58):

$$B/C_{ilj} = \frac{0.5 R_{ilj} W_A}{365 P_i} \quad (31)$$

where B/C_{ilj} = benefit to cost ratio for stocking the l^{th} unit of item i at base j ,

0.5 = ratio of NORS items to NORS aircraft,

R_{ilj} = NORS reduction by stocking the l^{th} unit of item i at base j ,

W_A = the worth of having an additional aircraft of type A for one year,

P_i = unit price of item i .

Dawson points out that W_A need not be actual values of worth but only relative values. If W_A represents only one aircraft type, then a constant of one may be used.

His idea of examining the decrease in expected NORS per dollar value invested is basically sound. However, it is not clear that his benefit/cost ratio model as developed, accurately describes the situation. The figures presented do not seem to support the 0.5 ratio of NORS items to NORS aircraft.

The Dawson approach, as previously stated, is a heuristic method. Only those items previously NORS are ever considered for improvement. If a system needs

frequent adjustments, as implied by Dawson's study, perhaps it needs replacement rather than patching.

Demmy's Study

In a study very closely related to Dawson's, Steven Demmy also explored NORS as related to supply availability. Drawing from Dawson's study, METRIC and the METRIC-LMI model, he arrived at essentially the same conclusions as Dawson did. Demmy noted that a major cause of NORS was the fact that Base Supply did not stock the needed item (5:2). His method of investing in additional stocks to prevent NORS is very similar to Dawson's. In developing a benefit/cost ratio model, he used actual aircraft cost in lieu of Dawson's W_A figure (5:15). This produces a dramatically higher benefit/cost ratio than Dawson's figures. Demmy concluded by suggesting that perhaps the Air Force should completely revise its policy for requirements computation (5:17).

Summary

Having examined the conventional model, a budget was developed. Comparing the conventional and METRIC models on the basis of Expected NORS in the perspective of a given budget led to an examination of alternative models.

Each of the alternative models moves to various means

and measures of improving the system availability. With this as a background and with the goal of improving availability, the methodology can now be developed.

CHAPTER III

METHODOLOGY

Overview

The data collection itself, variables which make up the data, and problems associated with the data collection will be discussed. Following this, a heuristic algorithm will be developed which attempts to maximize availability. Availability is defined as the number of units of a weapon system at any given base that are capable of performing their designated missions. A comparison of the conventional, METRIC, and heuristic availability models is then presented. Upon completion of the availability algorithms, a brief synopsis of the research procedure will be provided. Finally, the models will be tested and validated.

Data Base

In order to utilize a simplified METRIC algorithm, the data base chosen should consist of a weapon system employed at only one base. The METRIC algorithm is designed to make optimal distribution of assets between several bases and the depot. The simplifying procedure of using only one base allows the assumption that all assets will be stocked at the base with the depot performing only as a repair

facility. The weapon system chosen that meets the one-base criterion is the Airborne Command and Control Capsule (ABCC) employed at Keesler AFB, Mississippi and belonging to the Tactical Air Command (TAC).

Candidate Items

The data base ultimately chosen was obtained from the maintenance shop chief for the ABCC (3). He provided a list of 65 components used in the operations of the ABCC. Expendable, equipment, and insurance type items were eliminated with the exception of one item to be discussed in the testing and validation section. It was critical to the research that only items of the master stock number or those that could be cross-referenced to a master stock number be used. This requirement resulted from the fact that AFLC only accumulates data based upon the master stock number (2). Utilizing the Master, Substitute, and Interchangeability Listing (D097) the remaining stock numbers were screened and factored out leaving 32 items which could be used in the models. See Table 1 for a list of the items and associated usage parameters. The object of the search for data was to find end item assets which contained no other reparable assets utilized in its repair. Only one item in the data base is used to repair another. We have chosen to ignore the fact that demand for this one item

ITEM	NSN	NOM	DDR	PBR	RCT	OST	DRT	COST	QPA
1	5895001559275	Matrix	.0001	.99	9.0	14.0	69.0	26574.00	1.0
2	5895001559354	Circuit Card	.0134	.99	8.0	18.0	70.0	401.70	39.0
3	5821008387051	Control	.0179	.99	4.0	24.0	38.0	484.80	2.0
4	5821008932906	Receiver	.2134	.99	4.0	19.0	43.0	13231.00	2.0
5	5820009062214	Filter	.0134	.66	3.0	10.0	50.0	4190.00	1.0
6	5895009062203	Control Fltr	.0067	.66	4.0	20.0	64.0	705.60	1.0
7	5821006308981	Control	.0067	.01	4.0	8.0	34.0	6696.00	2.0
8	5821006308983	Rec Rad	.0988	.95	4.0	14.0	39.0	5640.00	2.0
9	5821006916299	Transmitter	.0404	.88	5.0	16.0	36.0	3557.00	2.0
10	5821006308978	Coupler	.0067	.33	5.0	26.0	40.0	1507.00	2.0
11	5821009178817	Coupler	.0359	.93	6.0	37.0	37.0	10952.00	4.0
12	5821006733101	Control	.0269	.91	4.0	16.0	45.0	200.00	1.0
13	5821006829336	Transmitter	.0898	.99	5.0	26.0	39.0	2626.00	1.0
14	5821006858366	Receiver	.1078	.99	5.0	22.0	41.0	1594.00	1.0
15	5821009338380	Control	.0112	.40	5.0	12.0	47.0	762.20	1.0
16	5821009338987	Receiver	.1280	.96	6.0	14.0	81.0	6386.00	1.0
17	5895001266344	Panel	.0966	.99	6.0	14.0	66.0	3708.00	1.0
18	5831008093180	Control	.1325	.98	5.0	10.0	37.0	575.00	13.0
19	5821004944292	Control	.0067	.99	4.0	29.0	40.0	1332.00	1.0
20	5821001387991	Receiver	.2516	.97	4.0	8.0	38.0	3434.00	2.0
21	5821001351701	Rec Trans	.0292	.92	4.0	17.0	36.0	9865.00	1.0
22	5895001198246	Matrix	.0089	.75	11.0	14.0	71.0	33512.00	4.0
23	5895001266341	Intercom	.0089	.87	6.0	14.0	81.0	9987.12	1.0
24	5895001198247	Matrix Black	.0001	.99	31.0	14.0	91.0	26381.00	1.0
25	5895000861138	Cont Unit	.0067	.99	10.0	14.0	70.0	19439.20	1.0
26	5895000861130	Control	.0001	.99	6.0	14.0	66.0	20480.00	1.0
27	5895004083725	Control	.0269	.99	5.0	14.0	65.0	2174.00	11.0
28	5895004083726	Control Unit	.0001	.99	6.0	14.0	66.0	3136.00	2.0
29	5895001310125	Power Supply	.0089	.50	6.0	9.0	68.0	3065.00	2.0
30	5895001310127	Recorder	.0067	.66	6.0	9.0	68.0	12188.00	2.0
31	4120009138899	Air Cond	.0157	.99	12.0	14.0	124.	3504.00	1.0
32	1680001308329	Seat Acft	.0001	.01	9.0	14.0	63.0	10383.00	2.0

SELECTED ASSETS
TABLE I

is dependent upon demand for the other and have treated both independently.

Item Usage Data

Before applying the models to the data, it is necessary that the usage data and its derivation be understood. The following variables are common to the models:

Daily Demand Rate (DDR): The daily demand rate is a forecast of expected usage. The time between demands is a reciprocal of the DDR.

Percent of Base Repair (PBR): The percentage of time, or probability that, a failed item can be repaired at base level.

Repair Cycle Time (RCT): In general terms, it is the time required to process an asset through the base repair facility and restore it to a serviceable condition.

Order and Ship Time (OST): The time required from requisition of an asset from the depot until it is received at the base. The majority of this time is in the transportation network. This is also known as lead time.

Unit Cost: The base price of an individual asset.

Quantity Per Application (QPA): The number of assets of any individual item required for operation of any individual weapon system.

Probability of Cannibalization: The likelihood, expressed as a probability, that any individual item, if

required on another end item, can be successfully removed and reinstalled. This is an important factor when the serviceable balance in the supply system is depleted.

Depot Repair Time (DRT): The time required for an asset to be repaired and placed back into the depot supply system.

Retrograde (RETRO): The standard time-frame utilized by AFLC to have the broken asset packaged, labeled, and transported to the depot repair facility.

The DDR, unit cost, and PBR were obtained from the UNIVAC 1050-II supply computer at Keesler AFB. The maintenance shop chief for the ABCC system provided the probability of cannibalization (3). The QPA, RCT, OST, and DRT, were obtained from the Data Collection System (D041) from AFLC headquarters.

Data Collection Problems

The original strategy for obtaining usable data was to utilize the Standard Reporting Designator (SRD) assigned to the ABCC as specified in TO 0020-2. It soon became apparent that a problem existed with this strategy. The SRD that some of the ABCC equipment was being reported against was in fact that of the aircraft carrying the capsule. This conflict concerning the SRD prohibited collection of reliable data. This appeared to be a problem at base level in failure to report data accurately. A second problem

arose in trying to utilize the SRD through the AFLC reporting system. The SRD for the capsule as assigned by TO 0020-2 is AEX. The base was reporting data on ALB but AFLC was collecting data on AE1. Standard reporting designators ALB and AE1 were both for C-130 aircraft. Having failed in the SRD approach, TAC headquarters was approached for assistance. The data obtained from TAC was helpful. However, it only represented those assets which had caused a NORS/NMCS condition within the past 24 months. Thus, the data did not necessarily represent a complete spectrum of reparable assets associated with the ABCC. Finally, unsatisfied with the data collected, the decision was made to contact the maintaining agency directly. Thus, a representative listing of repair cycle assets was obtained. Inquiries from the base supply UNIVAC 1050-II were also obtained. Inquiries into the DO41 system at AFLC revealed that nearly fifty percent of the master stock numbers had no data collected. This limited the number of items which could be used since complete data was unavailable.

Heuristic Availability Algorithms

Availability, as previously defined, is the number of units of a weapon system at any given base that are capable of performing their designated mission. The conventional and METRIC algorithms have been developed and are ready for application to the data. To use the data further, it

was necessary to develop a heuristic approach to buying the assets. Therefore, three models were developed. Each model considered expected NORS aircraft with full cannibalization. The first model is based on the pacing item. A pacing item is defined as that item which has the highest rate of expected backorders. The stockage algorithm minimizes the maximum expected backorders on any item. The pacing item algorithm operates by evaluating the expected backorders for each item given zero stockage of the item. The item with the largest number of expected backorders is identified and chosen for stockage. This process is repeated sequentially; that is, assets are bought one at a time where the criterion is the asset with the largest number of expected backorders, until a budget constraint is met. This algorithm was programmed in FORTRAN and is included in Appendix A as SUBROUTINE PACBUY.

The next model developed was on the basis of purchasing the item that created the greatest decrease in the expected NORS aircraft (ENA). This was found by calculating the fill rate for each item, given zero stockage, and hypothetically increasing the stockage of each item by one unit to evaluate its effect on fill rates and hence on availability. A stockage of one more unit of the item which had the largest decrease in ENA was bought, and the budget and stockage records were updated. This process was repeated until the budget was exhausted. See Appendix

A for this model under SUBROUTINE NORS.

The third heuristic procedure developed was similar to the second in that it also considered the expected number of NORS aircraft assuming full cannibalization. In this procedure, each incremental asset purchased was determined to be the asset which provided the greatest reduction in expected NORS aircraft per dollar spent. This procedure as coded in FORTRAN is included in Appendix A as SUBROUTINE NORCOS.

Testing, Validation, and Verification

It is necessary to insure that the data and stockage models provide output that is valid and reliable. As a first step in insuring reliability, the data were screened in an attempt to eliminate any bias. In every case where variables in the models were reported to the D041 system and also maintained by the UNIVAC 1050-II, and there was a difference, the D041 value was used. This occurred for the RCT and OST. As a further test to determine the validity and accuracy of the conventional model as represented by this research, the stockage levels computed in this research were compared to those reported by the base. Of the 32 items used, only two differed. This resulted from use of data based on the D041 system. Further validation of the METRIC model revealed that there is an error in the expected backorder computation because depot delay time is

not independent of demands as is assumed. METRIC indicates that assets should be split between the base and depot, when in fact it can be shown that with only one base user it is optimal to place all assets at the base. This correction was made in a computer simulation of the METRIC process in which the item with the highest DDR was used. This simulation was made using A. Alan B. Pritsker's system known as QGERT. This simulation places four assets at the base and none at the depot. It provided an expected backorder of .0215 with a standard deviation of .0032. The conventional model which also places four assets at the base and none at the depot provides an expected backorder rate of .02025. As previously mentioned, items which are used at only one base should not be stocked anywhere other than at that base. Therefore, the corrected simulation of METRIC would provide a lower backorder figure than the original METRIC algorithm would. Since the conventional model can provide a lower backorder figure than the corrected METRIC simulation, then splitting the allocation between the base and the depot as suggested by the original METRIC, is shown not to provide a lower figure than the conventional.

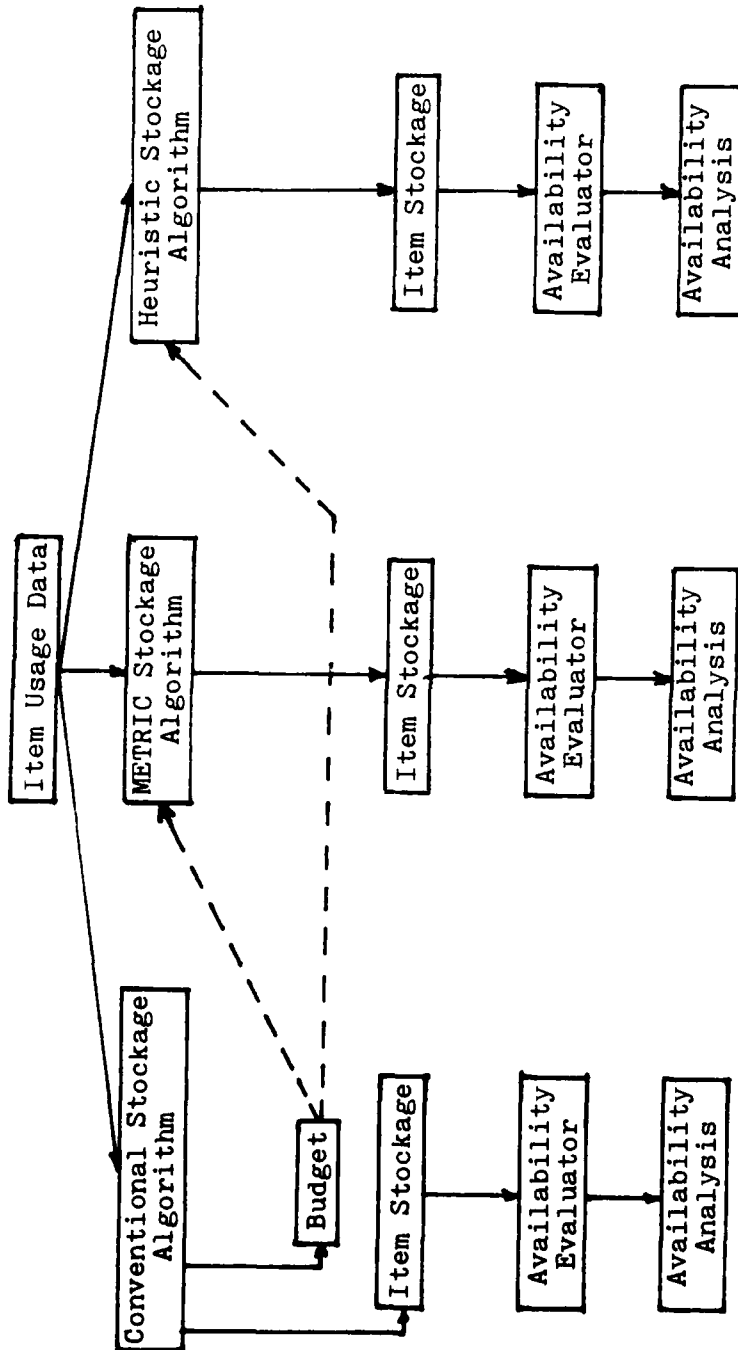
Outline of Research Procedure:

With the item usage data and the conventional model, a monetary figure was found which represents the total

cost of all assets which would be stocked using this model. This dollar value was termed the "budget" which became the monetary constraint for evaluation of all models. Determination of the budget was followed by computation of system backorders. System backorders represents the total number of times that demands exceed assets. Once system backorders were derived, three expected NORS aircraft (ENA) values were computed. One was based on full cannibalization. Another was an approximate ENA based on no cannibalization, and the last was an exact ENA with no cannibalization. The ENA values are used as a measure of availability.

Using the budget established in the conventional model and the item usage data, the METRIC model was evaluated. Again, a system backorder figure and three ENA values were obtained. This same procedure was followed for each of the heuristic models using the same inputs. This provided a comparison of all models based upon the same constraints.

As a final step in the research, the METRIC algorithm and the best heuristic model (NORCOS) were compared. The comparison was based upon ENA and employed a sensitivity analysis. The sensitivity analysis consisted of evaluating system availability where the budget constraint was varied from a budget of zero to a budget of 150% of the conventional budget. The research procedure is diagrammed in Figure 2.



The Availability Analysis provides:

1. Backorder matrix,
2. Probability of N NORS aircraft,
3. Probability of all aircraft being NORS,
4. Expected NORS aircraft based on full cannibalization and no cannibalization,
5. System backorders,
6. Total cost.

Figure 2. Research Procedure

CHAPTER IV

RESULTS

Introduction

The purpose of this chapter is the presentation of the results. Both graphic and tabular results will be presented and explained.

System Performance With Conventional Budget Constraint

Table 2 shows the results of each stockage algorithm when using the total inventory investment determined by the conventional model as a budgetary constraint. The baseline column shows the results that management could expect from the system if no assets were maintained in inventory. An asset that failed would create an NMCS condition which could only be satisfied by repair of the asset and re-installation upon the aircraft.

The value representing total inventory investment in dollars varies due to the process by which each algorithm determines the next asset to be purchased. Each algorithm is performing under a monetary constraint equal to the conventional model. Assets are purchased one at a time until the point is reached where the purchase of one more asset would exceed the constraint.

	Baseline	Conven- tional	METRIC	Pacing Item	NORS Im- provement	Cost Effec- tive NORS
Total Inventory Investment (\$)	\$0	\$205715	\$187712	\$204525	\$192278	\$187402
Total System Expected Backorders	12.26514	1.3259	.880294	1.704397	1.146963	.892994
System Availability (Expected Percentage Available)						
Assuming Full Cannibalization	73.8%	90.3%	92.6%	89.4%	91.3%	92.6%
Assuming No Cannibalization	20.5%	84.6%	89.5%	80.7%	86.6%	89.4%
Approximate						
Exact	21.2%	85.0%	89.8%	81.4%	86.9%	89.7%

COMPARISON OF INVENTORY SYSTEM PERFORMANCE
WITH CONVENTIONAL BUDGET CONSTRAINTS

TABLE 2

System availability represents a percentage of the total number of aircraft which would be available at any time. This percentage is determined by taking the total number of aircraft and subtracting the number of expected NORS aircraft. This value is then divided by the total number of aircraft and multiplied by 100 to obtain a percentage.

Analysis

The conventional dollar value shown in Table 2 represents the total dollar value of all assets stocked. The table further shows that when no cannibalization is considered, the availability is always worse than when cannibalization is considered. This is even more pronounced when the baseline values are compared. The approximate availability is always worse than the exact. Thus, when no cannibalization is to be considered as an alternative, the results of the exact procedure should be considered. The total expected system backorders are minimized by the METRIC algorithm.

As shown in Table 2, when given a budget equal to that of the conventional model, the Pacing item is worse than either the METRIC or conventional algorithms whether full cannibalization or no cannibalization is considered. Under the same conditions, the NORS Improvement algorithm is better than the conventional but worse than METRIC. When the

budgetary constraint equals the conventional budget, the Cost Effective NORS algorithm provides a slightly better availability than does METRIC with full cannibalization. The values in the table appear the same due to rounding.

Table 3 displays the various stockage positions of the conventional, METRIC, and Cost Effective NORS algorithms. The conventional values are based upon standard formulas from AFM 67-1 and provide only a target service level of support. The METRIC procedure considers the cost of each item and its effect on system backorders. The Cost Effective NORS algorithm considers the cost of each item, its quantity per application, and its effect on system availability.

System Performance With Budgetary Constraint 150% of the Conventional Budget

Table 4 displays the system performance based upon a budgetary constraint of 150% of that of the conventional budget. The total inventory investment in dollars varies due to the criteria for purchase of each asset by the algorithms. System availability is determined in the same way as in Table 2.

Analysis

The total expected system backorders is minimized by the METRIC algorithm. When no cannibalization is consider-

TABLE 3

COMPARISON OF STOCKAGE POSTURES
WITH THE CONVENTIONAL BUDGET CONSTRAINT

National Stock Number	Unit Cost	QPA	Conven- tional	METRIC	Cost Effec- tive NORS
5895001559275	26574.00	1	0	0	0
5895001559354	401.70	39	1	2	2
5821008387051	484.80	2	1	1	1
5821008932906	13231.00	2	3	2	2
5820009062214	4190.00	1	1	2	2
5895009062203	705.60	1	1	2	2
5821006308981	6696.00	2	1	2	1
5821006308983	5640.00	2	2	2	2
5821006916299	3557.00	2	1	2	2
5821006308978	1507.00	2	1	2	2
5821009178817	10952.00	4	1	1	1
5821006733101	200.00	1	1	3	3
5821006829336	2626.00	1	2	2	2
5821006858366	1594.00	1	2	3	3
5821009338380	762.20	1	2	3	3
5821009338987	6386.00	1	3	3	4
5895001266344	3708.00	1	2	3	3
5831008093180	575.00	13	2	4	4
5821004944292	1332.00	1	0	1	1
5821001387991	3434.00	2	4	4	4
5821001351701	9865.00	1	1	1	1
5895001198246	33512.00	4	1	0	0
5895001266341	9987.00	1	0	1	1
5895001198247	26331.00	1	0	0	0
5895000861138	19439.20	1	1	0	0
5895000861130	20480.00	1	0	0	0
5895004083725	2174.00	11	1	1	1
5895004083726	3136.00	2	0	0	0
5895001310125	3065.00	2	2	2	2
5895001310127	12188.00	2	0	1	1
4120009138899	3504.00	1	1	1	1
1680001308329	10383.00	2	0	0	0
Total Assets Purchased			38	51	51

	METRIC	Pacing Item	NORS Improvement	Cost Effective NORS
Total Inventory Investment (\$)	\$297224	\$290713	\$299173	\$294159
Total System Expected Backorders	.228357	.441955	.441405	.238361
System Availability (Expected Percentage Available)				
Assuming Full Cannibalization	97.5%	95.7%	95.6%	97.4%
Assuming No Cannibalization				
Approximate	97.1%	94.6%	94.6%	97.0%
Exact	97.2%	94.8%	94.7%	97.1%

COMPARISON OF INVENTORY SYSTEM PERFORMANCE WITH A BUDGET
CONSTRAINT OF 150% OF THE CONVENTIONAL BUDGET

TABLE 4

ed, the availability is always worse than with cannibalization. With the higher budgetary constraint and full cannibalization, the METRIC algorithm now provides a slightly better availability than the Cost Effective NORS algorithm.

Sensitivity Analysis

In order to explore the behavior of the METRIC and Cost Effective NORS algorithms across the range of total inventory investment constraints, the expected number of NORS aircraft was estimated as each algorithm added assets to its cumulative inventory posture.

Figure 3 shows the expected NORS aircraft for the METRIC and Cost Effective NORS algorithms when full cannibalization is assumed. The curves are plotted based upon the expected NORS aircraft after the purchase of each asset. The expected NORS aircraft provided by the conventional algorithm is worse than with either METRIC or Cost Effective NORS.

Figure 4 shows the expected NORS aircraft for the METRIC and Cost Effective NORS algorithms with no consideration for cannibalization. The curves in this graph are plotted for each incremental purchase of \$50,000 in assets. The METRIC algorithm performs better until approximately \$170,000 has been spent. At this point, the Cost Effective NORS provides a lower expected NORS aircraft. Finally, at approximately \$260,000, the difference in expected NORS

Sensitivity Analysis:
System Availability Assuming Full Cannibalization
Provided by METRIC and Cost Effective NORS
Algorithms

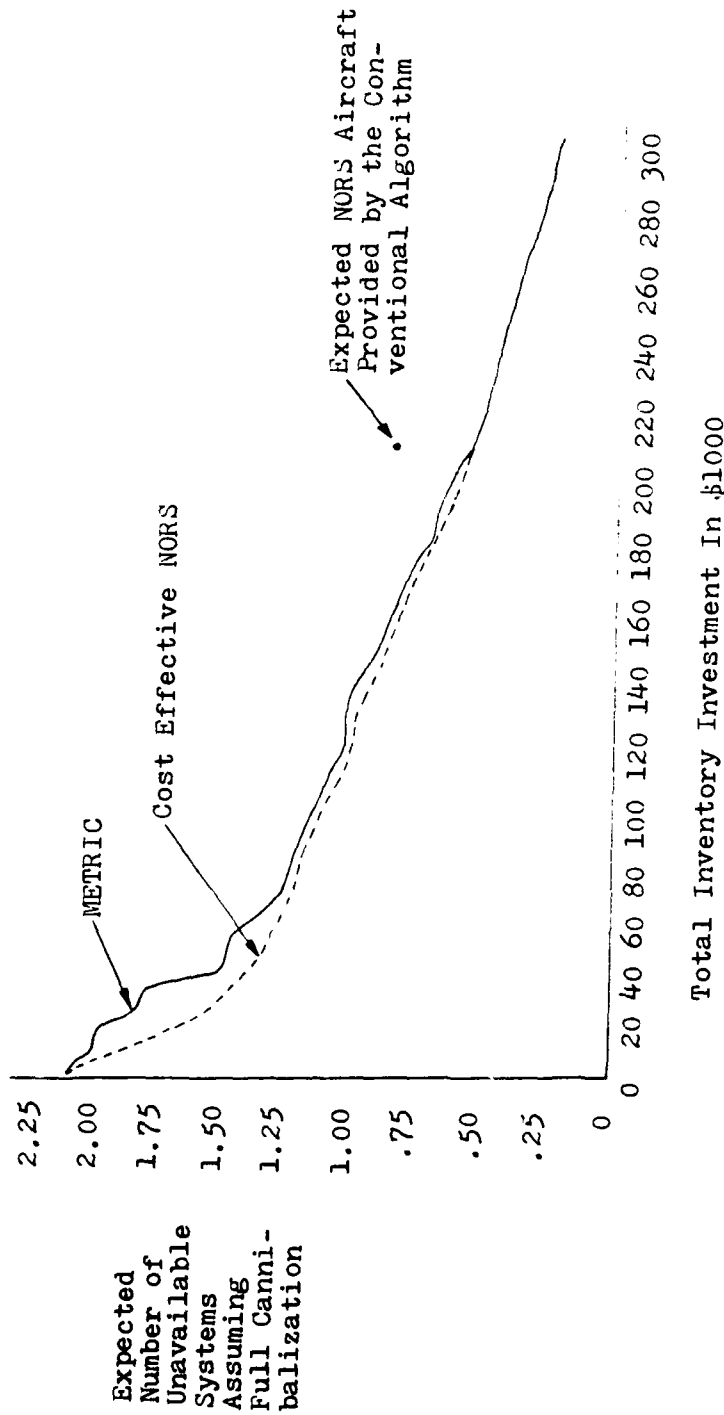


Figure 3. Sensitivity Analysis

System Availability Assuming No Cannibalization
 Provided by the METRIC and Cost Effective NORS
 Algorithms, Utilizing the Exact Availability
 Computation

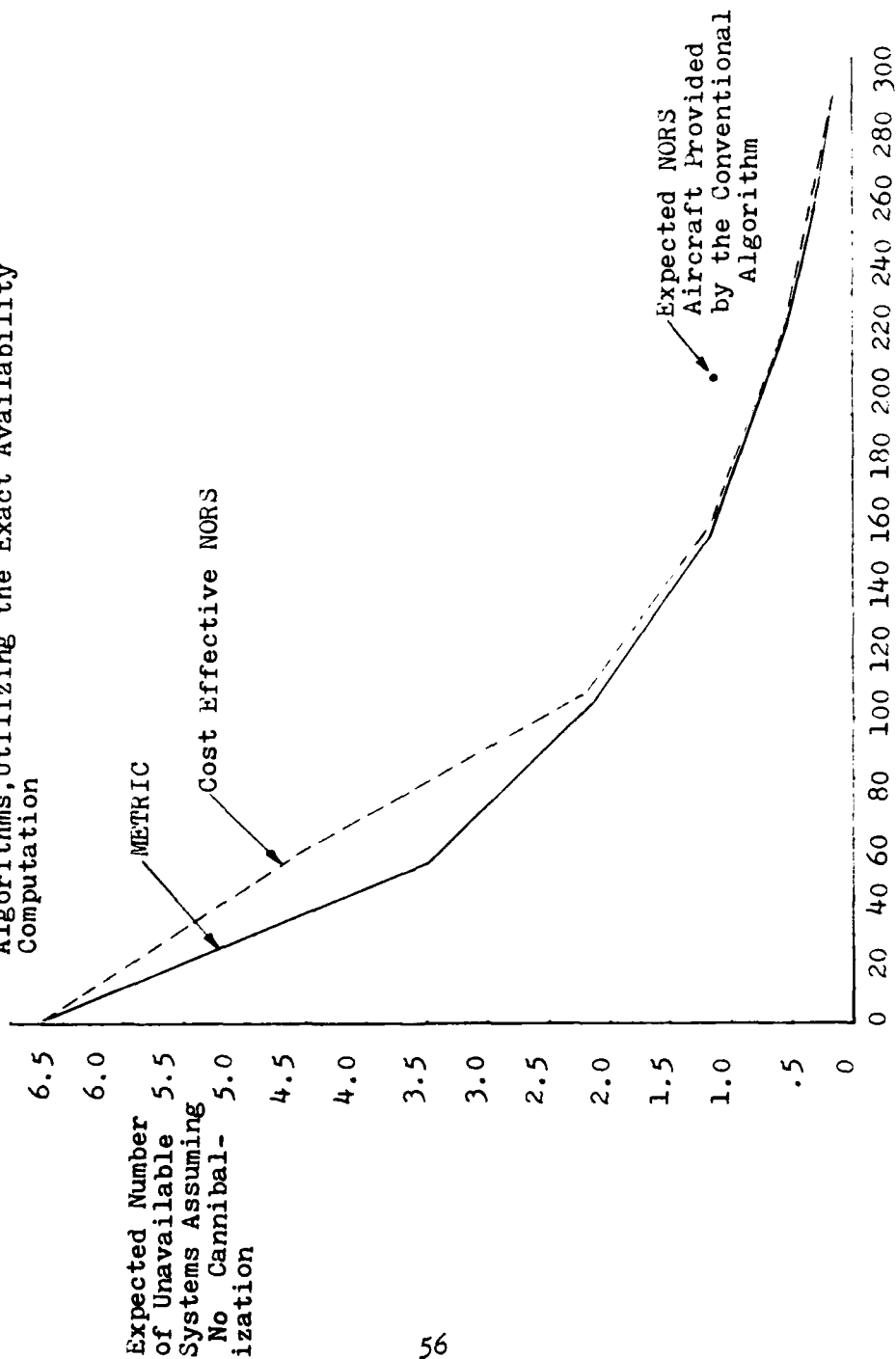


Figure 4. System Availability

aircraft becomes insignificant.

Research Questions

Research question one was concerned with the level of availability that the conventional model could provide. Assuming full cannibalization, 90.3% of the fleet would be available at any given time. This is shown in Table 2. Table 2 also shows that if the decision is not to cannibalize, the best availability to be expected would be 85.0%. These figures provide a base line against which the other models can be compared.

Research question two concerned the level of availability that the METRIC algorithm could provide. Table 2 shows that when the METRIC algorithm uses the conventional budgetary constraint an availability of 92.6% of the fleet could be expected at any given time. This is assuming full cannibalization. When the decision is made not to cannibalize, the best availability would only be 89.8%.

Research question three concerned whether any of the heuristic algorithms could provide a greater availability than the METRIC and conventional algorithms. Table 2 shows that when given a budgetary constraint equal to the conventional budget, the Pacing Item algorithm is the only one which does not perform better than the conventional algorithm. The Cost Effective NORS algorithm performs slightly better than METRIC although the percentages are

rounded to the same value. Both the Pacing Item and NORS Improvement algorithms are inferior to METRIC. Sensitivity analysis further indicates that at relatively high levels of investment (compared to the conventional investment) the system availabilities provided by the METRIC and Cost Effective NORS algorithms are essentially the same. At relatively low levels of investment, the Cost Effective NORS algorithm out-performs METRIC with respect to availability considering full cannibalization. METRIC out-performs the Cost Effective NORS procedure with respect to availability considering no cannibalization.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary of the Research

The major emphasis in this research has been the examination of weapon system availability provided by Air Force logistics. Realizing that both now and in the future, money will be a limiting factor to the performance of the supply system, it was not known what level of availability the current algorithm, that of METRIC, or any of the heuristic algorithms could provide.

As an outgrowth of this lack of knowledge concerning availability, three research questions were formulated. Question one involved the level of availability that the conventional algorithm could provide. Question two involved the level of availability that the METRIC algorithm could provide. Question three was concerned with whether any of the heuristic algorithms could provide a higher level of availability than METRIC or the conventional algorithms.

The methodology used to complete the research involved finding the total dollar value of inventory stocked under the conventional model. This total dollar value was then used as the budgetary constraint for all of the other

algorithms. Expressions for system backorders and expected NORS aircraft were developed to be used as performance measurements of each model.

To simplify the comparison of the models, a system which existed in an environment of one base and one depot was utilized. The system which met this requirement was the ABCC capsule.

The results of the research are that, for the weapon system under investigation, the conventional algorithm can provide an expected availability of 90.3%. The METRIC provides for 92.6% availability and the best heuristic algorithm also provides for 92.6%.

Conclusions of the Research Effort

It should be noted that although the conclusions reached are strongly supported by the data, the sample size of the data base is small. Larger sample sizes may lead to different conclusions.

The METRIC algorithm out-performs the conventional model in terms of expected backorders. Table 2 shows that expected backorders under the conventional are 1.3259, while under METRIC they are .880294. METRIC also provides for moderate improvement in system availability whether cannibalization is considered or not. Referring again to Table 2 and assuming full cannibalization, we see that the conventional algorithm provides for 90.3% availability

while METRIC provides for 92.6%. When assuming no cannibalization, the values are 85.0% and 89.8% respectively.

The conventional algorithm is non-optimizing. On the other hand, METRIC is designed to minimize expected backorders. When trying to maximize availability, the heuristic procedure of Cost Effective NORS can provide for a greater availability than METRIC. However, significant differences between the two can only be found when utilizing an extremely low budgetary constraint. Table 2 shows that the availability is nearly the same for each but total system backorders are higher under the Cost Effective NORS algorithm.

The Pacing Item model could not perform as well as the conventional model in any performance measure. This result is counter-intuitive. It would seem reasonable that any algorithm which strives to purchase assets based upon the item creating the most backorders would provide greater system availability than a model which only provides a target service level. This is not the case; the conventional algorithm provides greater system availability than the Pacing Item algorithm.

Managerial Implications

The results and conclusions reached thus far should be satisfying to USAF management. Management recognized that a non-optimizing algorithm, such as the conventional,

could probably be improved upon. Therefore, after considerable research and testing, Phase I of the METRIC algorithm was implemented. The conclusions reached in this research support the opinion that METRIC by minimizing expected backorders, can provide greater weapon system availability than that which is provided by the conventional model.

Cannibalization is a management decision. System availability is always greater when management exercises the option to cannibalize. Thus, the maintenance cannibalization policy is a key factor in the support provided for mission accomplishment.

Significant Methodological Issues

Several problems were encountered in the data collection phase of the research. One problem was a certain amount of ambiguity concerning the standard reporting designator. This ambiguity prevented retrieval of the data based solely upon the standard reporting designator. Another problem was encountered with the data collection system of AFLC. AFLC stores data based upon the master stock number. However, many of the stock numbers obtained as masters had no data available.

When evaluating a weapon system for availability in an environment assuming no cannibalization, the size of the fleet and the levels of stockage become very important.

The approximate measure of availability developed by the Logistics Management Institute was designed for systems having a large fleet and high asset stockage. As the size of the fleet and stockage of assets decreases, the accuracy of the LMI method is diminished. When the fleet is small and assets are limited, the exact method of availability is more appropriate.

Suggested Areas of Further Research

The research performed here encountered certain problems. Some problems were diminished through simplification of the approach while others required a great deal of effort to overcome. One simplification was finding a single base, single depot system. An area of further research would be to perform the same kind of marginal analysis with multi-base users.

An algorithm called MOD-METRIC (11) is designed to minimize expected backorders for indentured items. Research should be performed which will evaluate this model in terms of availability.

Each of the items used as data for this research had 100% feasibility of cannibalization. Further research should consider the impact of stockage levels when the feasibility of cannibalization varies from zero to 100% for each item.

One of the problems encountered with the data collec-

tion was a lack of information from AFLC's data collection bank. Some master stock numbers had no information available. An area of further research would be to evaluate the management information system between the bases and AFLC.

Final Comments

The significance of performing this research and of the conclusions reached lies with the ever-changing environment of DOD weapon systems and the tightening of budgetary constraints. Management must ensure that every dollar spent achieves maximum mission accomplishment. With new weapon systems evolving and new methods for requirements determination and distribution of assets being developed, it is imperative that management be informed of system performance. Availability will remain the most appropriate performance measure for the inventory system.

APPENDIX A
FORTRAN SUBROUTINES

```

PROGRAM THESIS (INPUT,OUTPUT)
COMMON ERM(32,21),UCOST(32),TSV(32),XDAT(32,5),
      PBA(32),BUDGET,ISM(32,5),FR(32,3),P(3),PNA(9),ENA
C THIS PROGRAM IS THE DISTRIBUTION ALGORITHM UTILIZED
C BY METRIC
      DETRO=15
      TO 910 I=1,32
      DO 900 J=1,20
      ERM(I,J)=0.0
      GOINT A
      FORMAT(1H1,I3,"ITEM",I14,"NSH",I20,"NOM",I11,"DDR",I17,
      "PR",I13,"FCT",I15,"OST",I14,"ORT",I13,"COST",I16,"OPA")
      DO 1000 ITEM=1,32
      READ 10,NSN,NOM,NOM1,NOM2,DDR,PBR,RCT,OST,ORT,
      UCOST(ITEM),OPA(ITEM)
      XDAT(ITEM,1)=DDR
      XDAT(ITEM,2)=PBR
      XDAT(ITEM,3)=RCT
      XDAT(ITEM,4)=OST
      XDAT(ITEM,5)=ORT
      FORMAT(113,3X,3A4,1X,FF.4,F4.2,3F4.1,F11.2,5X,F3.1)
      PRINT 11,ITEM,NSN,NOM,NOM1,NOM2,DDR,PBR,RCT,OST,
      UCOST(ITEM),OPA(ITEM)
      FORMAT(1H,15,2X,I13,2X,3A4,2X,F4.2,2X,F4.2,2X,
      F4.1,2X,F4.1,2X,F4.1,2X,F4.2,2X,F4.1)
      ENQ=(1.0-PBR)*DDR
      ENQ=EFFECTIVE DEPOT DEMAND
      INT=ORT+DETRO
      INT=DEPOT DELAY TIME
      RT=DEPOT REPAIR TIME
      XHU=ENQ*(PBR+RCT)+((1-PBR)*(OST+DJT)))
      XHU=THE AVERAGE NUMBER OF ITEMS FOR PIPELINE RE-SUPPLY
      TO 500 JI=1,20
      J=JI-1
      DEFSETS WERE REQUIRED TO OBTAIN THE PROPER STOCKAGE
      DEFCTO OF ERM MATRIX

```

```

      NR=I
      ERQ=1.0
      ERQ=EXPECTED BACKORDERS
      NPB=NB+1
      DO 35 K=NBP,51
      DELTA=((K-NB)*XPS(K,XMU))
      DELTA=CHANGE IN BACKORDERS
      ERQ=ERQ + DELTA
      ERQ(ITEM,JI)=ERQ
      ERQ=EXPECTED BACKORDER MATRIX GIVEN THE ITEM AND DIV STOCKED
      CONTINUE
1000 PRINT 1001
      ERQ=AT(1H0)
1001 PRINT 1515
1515 FORMAT(1H1," EXPECTED BACKORDER MATRIX ")
      ERQ=0
      ERQ=USED TO CALCULATE THE SYSTEM BACKORDERS
      DO 1500 I=1,32
      TSV(I)=0
      ERQ=ERQ+EBM(I,1)
1500 PRINT 1501, (EBM(I,J),J=1,10)
1501 FORMAT(1H ,10F10.6)
      PRINT 1005
1005 FORMAT(1H0)
      PRINT 2110,SB7
2000 ERQ=AT(1X," SBZ EQUALS ",F10.6)
      CALL NORSEV
      CALL CONVEN
      BUDGET=310000
      CALL METEUY
      CALL PACEUY
      CALL MORS
      CALL NORCOS
      PRINT 1601
1601 FORMAT(1H1,"ITEM",I9,"CONV",I13,"MET",I17,"NORCOS",

```



```

31 RCT=XVAL(ITEM,3)
    DST=XVAL(ITEM,4)
    RPT=XVAL(ITEM,5)
    DO=((1.1-PRR)*DDK*(DRT+RETRO+30))+.5
    DO=REPOT QUANTITY
    DO=((1.1-PRR)*DST)+(PRR*RCT))*DDR
    THE STANDARD FORMULA
    DO=RO+SOFT(3.1*80)
    THE SAFETY LEVEL FORMULA
    DO=0
    IF(UCCOST(ITEM).LT.750.(P) GO TO 18
    DO=.5
    GO TO 15
    DO=.9
    DO=0
    DO=0
    DO=BASE QUANTITY
    BUDGET=BUDGET+(UCCOST(ITEM)*(RO+DO))
    ALLOWS FOR ACCUMULATION OF TOTAL AMOUNT INVOLVED
    WITH THE STOCKAGE
    ISV(ITEM)=DO+RO
    ISV(ITEM,1)=DO+30
    INDEX=ISV(ITEM)+1
    INDEX=ISV(ITEM,INDEX)
    DO=DO+FR
    PRINT 71,ITEM,NO,DO,BUDGET,ERR,SBO
    FORMAT(1X," ITEM ",15," NO STOCK ",15," DEP QTY ",
:15," TOT SCENT ",F10.2," EXP 9.0.",F10.5," SYS R.O. "
:510.5)
    CONTINUE
    CALL HNPSEV
    PRINT 71
    FORMAT(1H," EXIT CONVEN ",//)
    GO TO 10

```

SUBROUTINE METBUY

```

SUBROUTINE METBUY
COMMON EBM(32,20),UCOST(32),ISV(32),XDAT(32,5),
      CPA(32),BUDGET,IS4(32,5),FR(32,8),P(8),PNA(9),ENA
      DIMENSION BCR(32)
      DIMENSION FRM(32,8,10)
      THIS PROGRAM WAS DEVELOPED BY RAND AND MINIMIZES
      EXPECTED BACKORDERS
      DO 1 I=1,10
      IV=I-1
      DO 5 J=1,32
      ISV(I)=IV
      CONTINUE
      CALL NORHPT
      NORHPT IS A SUBROUTINE WHICH COMPUTES THE FILL RATES
      DO 8 J=1,8
      DO 9 K=1,32
      FRM(K,I,I)=FR(K,J)
      CONTINUE
      PRINT *
      FORMAT(1H1," METBUY OUTPUT ",//)
      DO 300 I=1,32
      ISV(I)=(0.0)
      CALL NORHPT
      NITEM=32
      SRO=0.0
      SPENT=0.0
      DO 200 I=1,NITEM
      SRO=SR0+EBM(I,1)
      SRO=SYSTEM BACKORDERS
      ROP(I)=(EBM(I,1)-EBM(I,2))/UCOST(I)
      ROR=RENEFIT COST RATIO OF HAVING ONE ADDITIONAL UNIT
      AT THAT ITEM. THIS IS BEFORE THE ITEM IS BOUGHT
      CHECK=51000
      DO 100 IASSET=1,210
      TEST=1.0
      NITEM=0

```

```

300 I=1,NITEM
   IF(PCR(I).LT.BEST)GO TO 300
   BEST=PCR(I)
   ITEM=I
   CONTINUE
   IF(ITEM.EQ.0) GO TO 1001
   CHECK=SPEN1+UCOST(ITEM)
   IF(CHECK.GE.BUDGET) GO TO 1001
   ISV(ITEM)=ISV(ITEM)+1
   SPEN1=SPEN1+UCOST(ITEM)
   SRO=SRO-(UCOST(ITEM)*BCR(ITEM))
   ISTOCK=ISV(ITEM)+1
   NEXT=ISTOCK+1
   PCR(ITEM)=(ERM(ITEM,ISTOCK)-ERM(ITEM,NEXT))/UCOST(ITEM)
   THIS IS THE PCF AFTER AN ITEM IS BOUGHT
   IF(NEXT.GT.19)PCR(ITEM)=-1.0
   ISTOCK=ISTOCK-1
   NEXT=NEXT-1
   DO 350 J=1,8
     P(J)=P(J)*ERM(ITEM,J,NEXT)/ERM(ITEM,J,ISTOCK)
     PNA(1)=P(1)
   DO 351 N=2,8
     PNA=N-1
     PNA(N)=P(N)-P(N)
     PNA(1)=1.0-P(8)
     PNA=0
   DO 352 N=1,8
     PNA=N-1
     PNA=0
     PNA=0
     PRINT 411,IASSET,ITEM,ISV(ITEM),UCOST(ITEM),SRO,
     $PENT,BEST,PNA
     FORMAT(1X,"ASSETS ",15," ITEM ",15," TOT BOUGHT ",15,
     $ " UNIT COST "F10.2," SRO "F10.4," SPENT "F10.2,
     $ " PCR "F10.8," RAND NORS "F10.5)
     IF(SPENT.LT.MCHECK) GO TO 1010
     CALL NORSEV

```

```

1011 4CHECK=HCHECK+5J000
      CONTINUE
      PRINT 999
      FORMAT(1H1," FINAL STOCKAGE POSITION ")
1012 DO 1002 I=1,NITEM
1013   IS4(I,2)=ISV(I)
      COST=UCOST(I)+ISV(I)
      INDEX=ISV(I)+1
      NEXT=INDEX+1
      FC=(ERM(I,INDEX)-ERM(I,NEXT))/UCOST(I)
1012 PRINT 1003,I,UCOST(I),ISV(I),COST,FC
1013 FORMAT(1X," ITEM ",I5," UNIT COST ",F10.2," TOT STKD ",
      F5," TOT COST ",F10.2," BENEFIT COST RATIO ",F1.8)
      CALL NORFSEV
      PRINT 61
1014 FORMAT(1H," EXIT METRUY ",//)
      RETURN
      END

      SUBROUTINE NORCOS
      COMMON ERM(32,20),UCOST(32),ISV(32),XDAT(32,5),
      PNA(32),BUDGET,IS4(32,5),FR(32,8),P(8),PNA(9),FNA
      THIS PROGRAM BUYS ASSETS BASED UPON THE GREATEST DECREASE
      IN EXPECTED NORCS AIRCRAFT PER DOLLAR SPEND
      DIMENSION FFM(32,8,10)
      PRINT 1
      FORMAT(1H1," NORCOS OUTPUT ",//)
      GOVTEN=0
      DO 1 J=1,10
      14=I-1
      DO 5 J=1,32
      ISV(J)=JM
      CALL NORNOT
      DO 8 J=1,8
      DO 9 K=1,32
      FFM(K,J,I)=FK(K,J)
      15 THIS IS THE FILL RATE FOR AN ITEM BASED UPON A LEVEL

```

SUBROUTINE NORCOS

```

C 10 11 STOCKAGE
C 10 12 CONTINUE
C 10 13 T=1,32
C 10 14 ISV(I)=C
C 10 15 CALL NOKNPT
C 10 16 TEST=FNA
C 10 17 UC=51000
C 10 18 IASSET=1,100
C 10 19 ITEM=0
C 10 20 DELTA=0
C 10 21 I=1,32
C 10 22 IM=ISV(I)+1
C 10 23 INP=IM+1
C 10 24 DO 1 J=1,8
C 10 25 P(J)=P(J)+FFM(I,J,INP)/FRM(I,J,IN)
C 10 26 PNA(1)=P(1)
C 10 27 DO 15 N=2,2
C 10 28 V=N-1
C 10 29 PNA(N)=P(N)-P(N)
C 10 30 PNA(3)=1.0-P(8)
C 10 31 TEST=0.0
C 10 32 DO 17 N=1,9
C 10 33 VA=N-1
C 10 34 TEST=TEST+(PA*PNA(N))
C 10 35 TEST=(TEST-TEST)/UCOST(I)
C 10 36 IF (TEST.LT.DELTA) GO TO 1A
C 10 37 DELTA=DTEST
C 10 38 ITEM=I
C 10 39 SAVE=TEST
C 10 40 DO 19 N=1,8
C 10 41 P(N)=P(N)+FFM(I,N,IN)/FRM(I,N,INP)
C 10 42 CONTINUE
C 10 43 IF (ITEM.EQ.1) GO TO 101
C 10 44 CHECK=SPENT+UCOST(ITEM)
C 10 45 IF (CHECK.GE.BUDGET) GO TO 101
C 10 46 ISV(ITEM)=ISV(ITEM)+1

```

```

30 SPENT=SPENT+UCOST(ITEM)
31 RST=SAVE
32 IN=ISV(ITEM)
33 INP=IN+1
34 DO 3 J=1,8
35 P(J)=P(J)+FRM(ITEM,J,INP)/FRM(ITEM,J,IN)
36 PRINT 31,LASSEI,ITEM,ISV(ITEM),BEST,SPENT
37 FORMAT(IX,"ASSETS",I5,"ITEM",I5,"NO STKO",I5,
38 "BEST",F10.6,"SPENT",F10.2)
39 IF (HC.GE.SPENT) GO TO 100
40 CALL NORSEV
41 HC=HC+ELC(1)
42 CONTINUE
43 DO 1 I=1,32
44 ISM(I,3)=ISV(I)
45 PRINT 106,1,ISV(I)
46 FORMAT(IX,"ITEM ",I5," NO STKO ",I5)
47 CALL NORSEV
48 PRINT 115
49 FORMAT(1H," EXIT NORCUS ",//)
50 RETURN
51 END

```

SUBROUTINE NORS

```

C DIMENSION FRM(32,24),UCOST(32),ISV(32),XDAT(32,5),
C BPA(72),BUDGET,ISM(32,5),FR(32,8),P(8),PNA(5),PNA
C THIS PROGRAM BUYS ASSETS BASED UPON THE GREATEST DECREASE
C IN EXPECTED NORS AIRCRAFT
C DIMENSION FRM(32,8,10)
C PRINT 2
C FORMAT(141," NORS OUTPUT ",//)
C SPENT=0
C DO 1 I=1,10
C PNA=I-4
C DO 2 J=1,32
C ISV(J)=1M

```

```

      CALL NORNPY
      DO 8 J=1,6
      DO 8 K=1,32
      FOM(K,I,I)=FRM(K,J)
      CONTINUE
      DO 12 I=1,32
      ISV(I)=0
      CALL NORNPY
      REST=PNA
      DO 100 IASSET=1,100
      ITEM=0
      DO 21 I=1,32
      IN=ISV(I)+1
      INP=IN+1
      DO 15 J=1,8
      P(J)=P(J)+FRM(I,J,INP)/FRM(I,J,IN)
      PNA(I)=P(1)
      DO 16 N=2,6
      N=N-1
      PNA(N)=P(N)-P(N)
      PNA(9)=1.0-P(8)
      TEST=1.0
      DO 17 N=1,9
      NA=N-1
      TEST=TEST+(NA*PNA(N))
      IF (TEST.GT.BEST) GO TO 10
      BEST=TEST
      ITEM=I
      DO 19 N=1,6
      P(N)=P(N)+FRM(1,N,IN)/FRM(1,N,INP)
      CONTINUE
      IF (ITEM.FO.1) GO TO 101
      CHECK=SPENT+UCOST(ITEM)
      IF (CHECK.GE.BUDGET) GO TO 101
      ISV(ITEM)=ISV(ITEM)+1
      SPENT=SPENT+UCOST(ITEM)

```

```

30  IN=ISV(ITEM)
    IMP=TN+1
    DO 77 J=1,8
      P(J)=P(J)+FRM(ITEM,J,INP)/FRM(ITEM,J,IN)
    PRINT 31,I,ASSET,ITEM,ISV(ITEM),PEST
31  FORMAT(1X,"ASSETS",15,"ITEM",15,"NO STKO",15,"PEST",
    15,"5,")
    CONTINUE
100  DO 100 I=1,32
    ISV(I,4)=ISV(I)
105  PRINT 100,I,ISV(I)
106  FORMAT(1H," ITEM ",15," NO STKO ",15)
    CALL NORSEV
    PRINT 11
110  FORMAT(1H," EXIT NORS ",//)
    RETURN
    ENH
SUBROUTINE PACBUY
COMMON FRM(32,20),UCOST(32),ISV(32),XDAT(32,5),
    CPA(32),BUDGET,ISM(32,5),FR(32,8),P(8),PNA(5),ENA
THIS PROGRAM BUYS ASSETS BASED UPON THE ITEM WHICH
CREATES THE GREATEST EXPECTED BACKORDERS.
PRINT 50
FORMAT(1H1," PACBUY OUTPUT ",//)
DO 500 I=1,32
  ISV(I)=0.0
  SPENT=0.0
  TCOST=0.0
  PER=0.0
  DO 100 J=1,200
    PEST=-1.0
    ITEM=0
  DO 200 J=1,32
    TN=ISV(J)+1
    ENA=FRM(J,IN)/CPA(J)
    ENA=EXPECTED NORS AIRCRAFT

```

SUBROUTINE PACBUY

```

C      ERM=EXPECTED BACKORDER MATRIX
C      QDA=QUANTITY PER APPLICATION
IF (ENA.LT.BEST) GO TO 200
TEST=FNA
ITEM=J
CONTINUE
IF (ITEM.EQ.0) GO TO 1000
CHECK=SPENT+UCOST(ITEM)
IF (CHECK.GE.BUDGET) GO TO 1000
IN=ISV(ITEM)+1
ISV(ITEM)=ISV(ITEM)+1
SPENT=SPENT+UCOST(ITEM)
PRINT 201,I,ITEM,ISV(ITEM),ERM(ITEM,IN),BEST
FORMAT(1X," ASSETS ",I5," ITEM ",I5," NO STKD ",
15," EXP B.O. ",F10.5," BEN COST RATIO ",F10.8)
201 CONTINUE
PRINT 299
FORMAT(1H1," FINAL STOCKAGE POSITION ")
DO 300 I=1,32
ISTOCK=ISV(I)
ISM(I,5)=ISV(I)
IP=ISTOCK+1
COST=UCOST(I)*ISTOCK
TCOST=TCOST+COST
ERM=ERM+ERM(I,IP)
PRINT 301,I,ISTOCK,COST,ERM(I,IP)
FORMAT(1H," ITEM ",I5," NUMBER STOCKED ",I5,
1" COST ",F12.2," EXPECTED BACKORDERS ",F10.5)
PRINT 302,TCOST,TER
FORMAT(1X//," TOT COST ",F12.2," TOT EXPECTED BACKORDERS ",
F10.5)
CALL MORSEV
PRINT 51
FORMAT(1H," EXIT PACBUY ",//)
RETURN
END

```

SUBROUTINE NORSEV

```

SUBROUTINE NORSEV
COMMON EBY(32,20),UCOST(32),ISV(32),XDAT(32,5),
:OPA(12),BUDGET,ISM(32,5),FR(32,8),P(8),PVA(9),ENA
THIS PROGRAM EVALUATES EACH OF THE STOCKAGE POSITIONS
FOR CANNIBALIZATION POLICY BASED UPON RAND, LMI, AND
A PESSIONISTIC POSITION,
RETRO=15
PRINT 10
FORMAT(1H," NORSEV OUTPUT ",//)
PRINT 11
FORMAT(18,"ITEM",T17,"NO",T26,"ONE",T36,"TWO",
:T45,"THREE",T55,"FOUR",T65,"FIVE",T75,"SIX",T85,"SEVEN")
PRINT 12
FORMAT(T16,"CANNIS",T26,"CANV",T35,"CANNIS",T45,
:"CANS",T56,"CANS",T66,"CANS",T75,"CANS",T86,"CANS")
DO 40 ITEM=1,32
NOR=XDAT(ITEM,1)
PAR=XDAT(ITEM,2)
RCT=XDAT(ITEM,3)
OST=XDAT(ITEM,4)
ORT=XDAT(ITEM,5)
OB=ISV(ITEM)
ODT=ORT+RETRO
DDT=DEPOT DELAY TIME
XMU=NR*((PBR/RCT)+((1-PBR)*(OST+ODT)))
F=0.0
ISLP=OR+1
DO 30 J=1,ISTOP
JJ=J-1
F=F+XPS(JJ,XMU)
FR(ITEM,1)=F
FR=FILL RATE PASSED UPON A POISSON FUNCTION
DO 25 K=2,8
KK=K-2
KM=K-1
FR(ITEM,K)=FR(ITEM,KM)

```

```

N=OPA(ITEM)
KL=KK*N
DO 30 J=1,N
M=ISV(ITEM)+KL+J
FR(IFM,K)=FR(ITEM,K)+XPS(I,XMU)
CONTINUE
CONTINUE
DO 50 N=1,8
P(N)=1
DO 45 ITEM=1,32
P(N)=P(N)*FR(ITEM,N)
P(N)=PROBABILITY OF A NORS
CONTINUE
PNA(N)=PROBABILITY OF N NUMBER OF AIRCRAFT NORS
PNA(1)=P(1)
DO 50 N=2,8
M=N-1
PNA(N)=P(N)-P(M)
PNA(9)=1.0-P(8)
DO 70 I=1,32
PRINT 100,I,(FR(I,N),N=1,8)
FORMAT(5X,I5,8F10.4)
PRINT 105
FORMAT(/)
DO 75 N=1,8
NA=N-1
PRINT 76,NA,P(N),PNA(N)
FORMAT(1X," NUM OF ACFT ",I3," PROB OF NORS ",
:F10.4," PROB OF N NORS ",F10.4)
PRINT 111,PNA(9)
FORMAT(16X," PROB ALL NORS = ",F11.4)
ENA=0.0
DO 117 N=1,9
NA=N-1
ENA=EXPECTED NORS AIRCRAFT BASED ON CANNIBALIZATION
ENA=ENA+(NA*PNA(N))

```

```

111 PRINT 111,ENA
    FORMAT(5X," EXPECTED NORS ACFT ",F10.4)
    PP=1.0
    DO 500 ITEM=1,32
        IND=ISV(ITEM)+1
        Q=QPA(ITEM)
        E=ERM(ITEM,IND)
        PP=PP*((1.1-(E/(8.0*Q)))*.3)
        ENA=8.0-(8.0*PP)
    PRINT 501,ENA
501 FORMAT(1X," EXPECTED NORS LMI VERSION ",F10.5)
    PP=1.0
    DO 500 I=1,32
        P2=0
        X=XDAT(I,1)*((XDAT(I,2)*XDAT(I,3))+((1-XDAT(I,2))*
            *(XDAT(I,4)+XDAT(I,5)+RETRO)))
        IYN=ISV(I)
        ISTOP=ISV(I)+(QPA(I)*8.0)
        DO 550 IN=1,ISTOP
            ID=IN-1
            IF(IN.LE.ISV(I)) Z=1.0
            IF(IN.GT.ISV(I)) Z=(1.0-((ID-IN)/(8.0*QPA(I))))*.0PA
            , (I)
            PQ=PQ+(7*XPS(ID,X))
            PP=PP*PQ
            ENH=8.0-(8.0*PP)
        PRINT 601,ENH
601 FORMAT(1X," HOURS EXPECTED NORS AIRCRAFT ",F10.4)
        TC=0
        SQ=0
        DO 700 I=1,32
            IN=ISV(I)+1
            TC=TC+(ISV(I)*UCOST(I))
            SQ=SQ+ERM(I,IN)
        PRINT 701,SQ,TC
701 FORMAT(1H," SYSTEM BACKORDERS ",F10.6," TOTAL COST ",

```

```

1F10.2)
PRINT 200
FORNAT(1H," EXIT NORSEV ",//)
RETURN
END

SUBROUTINE NORNPT
COMMON EBM(32,20),UCOST(32),ISV(32),XOAT(32,5),
QPA(32),BUDGET,ISM(32,5),FR(32,9),P(8),PVA(9),ENA
THIS PROGRAM IS UTILIZED TO COMPUTE THE FILL RATE
BASED UPON EACH STOCKAGE POSITION,
RETRO=15
DO 40 ITEM=1,32
DOR=XOAT(ITEM,1)
POR=XOAT(ITEM,2)
ROF=XOAT(ITEM,3)
OSF=XOAT(ITEM,4)
ORF=XOAT(ITEM,5)
OR=ISV(ITEM)
DOT=DOT+RETRO
X4U=ONR*((POR*ROF)+(1-POR)*(OST+JJ))
F=9.0
ISTOP=OB+1
DO 30 J=1,ISTOP
JJ=J-1
F=F+XPS(JJ,X4U)
FR(ITEM,1)=F
DO 25 K=2,8
KK=K-2
K4=K-1
FR(ITEM,K)=FR(ITEM,KH)
N=QPA(ITEM)
KL=KK*N
DO 30 J=1,N
M=ISV(ITEM)+KL+J
FR(ITEM,K)=FR(ITEM,K)+XPS(M,X4U)

```

SUBROUTINE NORNPT

AD-A103 255 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL--ETC F/G 5/1
AN EMPIRICAL INVESTIGATION OF THE EFFECTS OF INVENTORY STOCKAGE--ETC(1)
JUN 81 J A DUKE, K W ELMORE
UNCLASSIFIED AFIT-LSSR-14-81

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2 OF 2

AD-A103 255



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25  CONTINUE
40  CONTINUE
    DO 50 N=1,8
      P(N)=1
      DO 55 ITEM=1,32
        P(N)=P(N)*FR(ITEM,N)
      CONTINUE
      PNA(1)=P(1)
      DO 58 N=2,8
        M=N-1
        PNA(N)=P(N)-P(M)
        PNA(9)=1.0-P(8)
        ENA=N.5
      CONTINUE
      DO 110 N=1,9
        NA=N-1
        ENA=ENA+(NA*PNA(N))
      CONTINUE
      RETURN
    END

116  FUNCTION XPS(N,X)
      IF(N)10,20,30
      PRINT 11
      FORMAT(1X," ERROR IN XPS FUNCTION ")
      STOP
      XPS=EXP(-X)
      RETURN
      XPS=EXP(-X)
      DO 75 I=1,N
        7=I
      XPS=XPS*(X/7)
      RETURN
    END

```

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