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DEPARTMENT OF THE NAVY
SUPPLY SYSTEMS COMMAND

RIM-AIR STUDY

OPERATIONS ANALYSIS DEPARTMENT

NAVY FLEET MATERIAL SUPPORT OFFICE
Mechanicsburg, Pennsylvania 17055

Report 155

RIM-AIR STUDY

PROJECT NUMBER 9321-E66

REPORT NO. 155

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DATE: JUN 30 1983

Abstract

Naval Supply Systems Command (COMNAVSUPSYSCOM) proposed the Repairable Integrated Model for Aviation (RIM-AIR) model to compute Aviation Consolidated Allowance List (AVCAL) requirements during the provisioning and AVCAL development processes at Navy Aviation Supply Office (ASO). The AVCAL is a consolidated listing of the range and depth of aeronautical material required by ships, Marine Air Groups (MAGs), and Naval Air Stations to support aircraft operations. RIM-AIR was designed to eliminate the dichotomy between the material availability goals and stockage criteria promulgated in OPNAVINST 4441.12A while complying with the policy established by DODIs 4140.45, 4140.46, and 4140.47. This report analyzes alternative range and safety level criteria for RIM-AIR, recommends specific alternatives and discusses issues relevant to the implementation of these recommendations.

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Executive Summary

1. Purpose. The Repairables Integrated Model for Aviation (RIM-AIR) was proposed by the Naval Supply Systems Command (COMNAVSUPSYSCOM) to eliminate the dichotomy between the material availability goals and stockage criteria promulgated in OPNAVINST 4441.12A. RIM-AIR was designed to comply with DODIs 4140.45, 4140.46 and 4140.47.

As developed by COMNAVSUPSYSCOM, RIM-AIR is a depth model. The RIM-AIR requirement specifically consists of an operating level, repair cycle level, order and ship time level, resupply delay time level, endurance level and safety level. To complete the model, range and safety level criteria must be selected. This study analyzed alternative range and safety level criteria for use with the depth model.

2. Approach. The cost and effectiveness of alternative range and safety level criteria were quantified. The range alternatives examined were the current range rules, range based on the depth computation, and range based on number of removals. The safety level alternatives were fixed protection against being out of stock, a simple variable protection procedure and an optimization of cost/effectiveness. A benchmark was established based on the range and safety level criteria currently used by the Aviation Supply Office (ASO).

The evaluation criteria used to compare alternatives were net and gross supply effectiveness. An analytical model of the repair and requisition processes was used to develop effectiveness statistics based on the item characteristics of the candidates for stockage. The completeness of the candidate data was quantified using Navy Maintenance and Material Management (3M) data. The accuracy of item characteristics was modeled statistically. Both factors were considered in the effectiveness computations. The candidate item data were extracted from the Allowance Requirements Registers (ARRs) used to construct the Aviation Consolidated Allowance Lists (AVCALs) for the USS CONSTELLATION and NAS Brunswick. These data contained a repair rate, attrition rate and turnaround time for each candidate. Order and ship time data were obtained from the Requisition Response Time Management Information System (RRTMIS) and Uniform Automated Data Processing System (UADPS) Level II Leadtime Process. Wartime and peacetime flying hour programs provided by ASO were used with these item characteristic to compute requirement quantities and forecast effectiveness.

3. Findings.

a. Repairables. The benchmark quantities almost completely filled the repair cycle, order and ship time and resupply delay time levels for both study activities. However, there was little left over for a safety level. Filling the safety levels provided the greatest increase in effectiveness. Adding the operating and endurance levels increased effectiveness but the cost per percentage point increase was higher.

The wartime gross effectiveness of the RIM-AIR quantities for the USS CONSTELLATION was below the OPNAVINST 4441.12A goal of 75% with the current range criteria and fixed protection. Stockage based on predicted removals above a threshold was found to be the best range criteria with fixed protection. The cost to meet the OPNAVINST 4441.12A goal with this range criteria and 85% fixed protection was $45.7M above the benchmark. This cost was reduced $15.1M by optimizing the safety level with the same range of items. Optimizing range and safety level lowered the cost another $3.3M. This still leaves a cost increment of $27.3M. This cost increment can be reduced by applying constrained order and ship times. If the constrained order and ship times used by ASO in their 2R/8R cog item initiative are used, the cost increment is reduced to $15.5M (in addition to $2.9M for the ASO 2R/8R initiative). These cost increments are minimums and could be higher when more accurate candidate data is used.

The peacetime gross and net effectiveness of the RIM-AIR quantities for NAS Brunswick were above the OPNAVINST 4441.12A goals of 65% gross and 85% net with the current range criteria and fixed protection. Eighty-five percent fixed protection produced a gross peacetime effectiveness of 71% at a cost $4.7M above the benchmark. Optimizing range and depth to this level of effectiveness lowered the cost to $2.3M above the benchmark. If the constrained order and ship times discussed above are used, the cost increment above the benchmark is $1.1M. As with the USS CONSTELLATION repairables, these costs are minimums.

b. Consumables. The benchmark quantities filled the order and ship time and resupply delay time levels for the USS CONSTELLATION. As with the repairables, there was little left over for a safety level. Filling the safety level increased effectiveness, but adding the operating level provided the greatest increase in performance. NAS Brunswick consumables were not examined because it is anticipated that requirements for Naval Air Station consumables will continue to be determined under Variable Operating and Safety Level (VOSL).

The wartime gross effectiveness of the RIM-AIR quantity for the USS CONSTELLATION was below the OPNAVINST 4441.12A goal of 75% with the current range criteria. This shortfall was due to the large number of demands for noncandidate items. The maximum gross effectiveness achievable with the ARR candidate data was 34%. Thus no range criteria could stock enough items to meet the goal. The range by depth criteria was found to stock the most items for a given cost with safety level computed with fixed protection. However, the range by depth criteria stocks almost all low cost items with predicted demand greater than zero. The current range criteria has the ability to differentiate among low cost items and is therefore preferable.

An analysis of the variable protection approaches failed to show any benefit over fixed protection. The large number of demands for noncandidate items and high variability of the candidate item characteristics negated the benefits of varying protection. Because fixed protection is simpler and performs as well, it is preferable.

4. Recommendations. The following recommendations are made as a result of this study:

- Use the optimization to determine both range and safety level for repairables.
- Use the current range criteria and fixed protection to determine safety level for consumables.
- Implement RIM-AIR in the ASO retail provisioning and UICP AVCAL development processes.

I. INTRODUCTION

OPNAVINST 4441.12A prescribes policy for the development and maintenance of aeronautical material requirements for ships, Marine Air Groups (MAGs) and Naval Air Stations (NASs). Criteria are provided that are currently used in the computation of the range and depth of stock required to support aircraft operations at these activities. Material availability goals are also specified. Previous analyses conducted by FMSO and ASO have concluded that the material availability goals cannot be achieved with the specified range and depth criteria. This dichotomy in policy was documented in reference (1), Appendix A. In response to this dichotomy, Commander, Naval Supply Systems Command (COMNAVSUPSYSCOM) proposed a pipeline model to eliminate the gap between the availability goals and the levels policies. The term pipeline refers to the queue of requirements that forms as not Ready for Issue (non-RFI) units enter the repair processes or demands for RFI units enter the requisition process. The number of non-RFI units undergoing repair is referred to as the repair pipeline. The number of requisitions to replace a non-RFI unit that cannot be repaired is the requisition pipeline.

The COMNAVSUPSYSCOM pipeline model was designated Repairables Integrated Model for Aviation (RIM-AIR) which is somewhat misleading since the pipeline approach can be applied to both consumable and repairable spares. It was designed to eliminate the dichotomy problem while complying with DODIs 4140.45 (Standard Stockage Policy for Consumable Secondary Items at Intermediate and Consumer Levels of Inventory), 4140.46 (Standard Stockage Policy for Repairable Secondary Items at the Intermediate and Consumer Levels of Inventory) and 4140.47 (Secondary Item War Reserve Requirements Development). The first two instructions establish procedures for computing Peacetime Operating Stock (POS) requirements. Specifically, an operating level, order and ship time level, and safety level are authorized for all demand-supported items and an added repair cycle level is provided for repairables. The third instruction addresses the War Reserve Material Requirements (WRMRs). Increments to the order and ship time, repair cycle and safety levels are authorized to satisfy wartime recurring demands over and above the peacetime demands. An additional Resupply Delay Time (RDT) level is also authorized to provide material coverage of anticipated delays in the wartime retail level supply pipeline. In addition to these levels, COMNAVSUPSYSCOM added a level of stock to RIM-AIR that assures a self-supporting capability for a prescribed period of time. This additional level is termed an "endurance delta" and the requirement for a self-support capability is established in OPNAVINST 4441.12A. Wartime demand is used to compute this level.

The POS, WRMR, and endurance levels are combined under RIM-AIR to produce a total depth of stock that may be expressed mathematically as follows:

$$\text{RIM-AIR Depth} = \text{OL} + \text{RCL}_w + \text{MAX}\left\{\begin{matrix}\text{OST}_p + \text{EDP}\\ \text{OST}_w + \text{RDT}\end{matrix}\right\} + \text{SL}$$

where

OL = operating level

RCL_w = repair cycle level computed with a wartime flying hour program

OST_p = order and ship time level computed with a peacetime flying hour program

EDP = endurance period support, level to assure a self-supporting capability to satisfy wartime demands for a prescribed period of time

OST_w = order and ship time level computed with a wartime flying hour program

RDT = Resupply Delay Time level

SL = Total safety level based on the sum of RCL_w and the MAX computation

The POS levels authorized by DODIs 4140.45 and 4140.46 may be separated from the total depth as follows:

$$POS = OL + RCL_p + OST_p + SL_p$$

where

RCL_p = repair cycle level computed with a peacetime flying hour program

SL_p = that portion of total safety level required to support peacetime flying hours

Similarly, the WRMR portion of the total depth consists of the following:

$$WRMR = (RCL_w - RCL_p) + (OST_w - OST_p) + RDT + SL_w$$

where

SL_w = that portion of total safety level required over and above SL_p to support wartime flying hours

Finally, the endurance delta represents the difference between OST_p + EDP and OST_w + RDT. Mathematically, it may be expressed as follows:

$$END\ DELTA = MAX \left\{ \begin{matrix} EDP - (OST_w - OST_p) - RDT \\ 0 \end{matrix} \right\} + SL_E$$

where

SL_E = that portion of the total safety level required over and above SL_W to support a wartime flying hour program over the endurance period

A detailed background discussion of the problems and events that led to the development of RIM-AIR is provided below.

RIM-AIR was developed as a mechanism for applying Department of Defense (DOD) guidelines to eliminate deficiencies in repairable requirements promulgated in the Aviation Consolidated Allowance List (AVCAL). The current OPNAVINST 4441.12A criteria that are used to compute AVCAL requirements do not provide support for the total pipeline at retail activities. The current requirement consists of a protected repair cycle level plus unprotected attrition support for a 90 day endurance period. There is no support for the requisition process, i.e., no order and ship time or resupply delay time levels. The OPNAVINST 4441.12A instruction states that replenishment of repairables will be on a one-for-one basis but does not provide an operating level. Since these levels are specifically authorized in the DODIs 4140.45 and 4140.46 RIM-AIR includes them along with an additional safety level for the order and ship time and resupply delay time.

The need for an Order and Ship Time level was recognized by Aviation Supply Office (ASO) which obtained funding for cognizance symbol (cog) 2R/8R material Order and Ship Time (OST) levels. This material has been bought and will be included in ship/MAG AVCALS starting in the summer of 1983. A program has been developed that provides ASO with a basic RIM-AIR capability that can be utilized to add the 2R/8R OST levels. Navy Fleet Material Support Office (FMSO) tasking for this effort was provided in reference (2) Appendix A. The 2R/8R OST levels being added by ASO only partially solve the deficiencies in the current requirements. COMNAVSUPSYSCOM has proposed that RIM-AIR be used to add additional levels as funding becomes available until the total RIM-AIR requirement is achieved. This will require implementing RIM-AIR in the different processes used to determine requirements during the life of a weapon system.

Requirements for the initial outfitting of a weapons system are determined during the provisioning process. There are currently multiple requirement models that may be selected by ASO to compute provisioning quantities. These models must comply with DODI 4140.42 which sets policy for the determination of initial requirements for secondary item spare and repair parts. RIM-AIR can easily be adapted to this directive by eliminating the safety level. The requirements generated during provisioning must be periodically revised to reflect operational experience. OPNAVINST 4441.12A states that ship/MAG requirements must be revised no less often than every 18 months or prior to deployment. Naval Air Station requirements must be revised at least every two years, or more frequently if required by changes on supported aircraft, installed equipment or ground support equipment. Revised requirements are generated by the ASO AVCAL process (re-AVCAL). This process is very complex and involves an extensive system of computer programs and labor intensive quality control procedures. FMSO is currently tasked with developing a Uniform Inventory Control Program (UICP) system to perform this function. Unlike the current AVCAL system which utilizes precomputed requirements, the UICP system will compute the requirements directly at the time of AVCAL production. UICP AVCAL requires a mathematical model to compute allowance quantities and the RIM-AIR model can readily meet this requirement.

The pipeline concept upon which RIM-AIR is based is extremely flexible. As mentioned earlier, this approach can be applied to determine consumable item requirements. While the FMSO dichotomy study concluded that the difference between consumables and repairables supports development of separate consumable and repairable models, it is desirable to develop these models within the same theoretical framework. Only two distinctions need to be made between consumables and repairables under the pipeline concept. First, consumables may be requisitioned in quantities greater than one. This means that the operating level may be greater than the quantity of one used for repairables. The operating level is easily determined using a Wilson Economic Order Quantity (EOQ). The second distinction is that since consumables are not repaired, they do not require a repair cycle level. With these two modifications, the mathematical formula presented earlier can be used to compute consumable requirements. There is a need for a consumable computation procedure to determine ship/MAG AVCAL requirements. Consumable retail requirements for Naval Air Stations are computed under Variable Operating and Safety Level (VOSL) procedures and it is envisioned that this will continue.

Two questions need to be answered before RIM-AIR is ready for implementation. First, how will the amount of safety level protection afforded each item be determined? The simplest answer to this question is to use a fixed level of protection for each item. The only drawback to this approach is cost. Cost can be reduced by varying protection according to the individual characteristics of the items. However, this raises the question as to whether a variable protection approach can be found that is workable in a production environment. The second question that needs to be answered is which items should be stocked? RIM-AIR as developed by COMNAVSUPSYSCOM is a depth model, but to be complete, it must be coupled with a range rule. One possibility is to use the current range criteria. The disadvantage of the current criteria is that attrition and repair demand are segregated and separate range criteria are applied to determine attrition and repair support. This splitting of demand results in nonstockage of items that would have been stocked had demand been combined. Simply combining demand does not solve the problem because different range rule concepts are currently applied to the attrition and repair segments. Stockage for attrition support is based on a demand threshold. That is, an item is stocked for attrition support if the forecasted demand is above a certain level. Stockage in support of the repair process is provided so as to provide 90% fixed protection against stockout in the repair pipeline. If a quantity of zero provides the required protection, the item is not stocked for repair support, otherwise it is stocked with the appropriate quantity. Therefore, an item is stocked if the depth model computes to one or more; in essence, the range is determined by the depth calculation.

In order to complete the RIM-AIR model for implementation, COMNAVSUPSYSCOM tasked FMSO by reference (3) Appendix A to study the two questions discussed above. The cost/effectiveness of alternative variations of the RIM-AIR model were to be evaluated. As the study progressed, it was decided that the impact of data inaccuracies should be considered in the evaluation. Reference (4) Appendix A provided COMNAVSUPSYSCOM with new resource and milestone estimates to consider this additional problem. Reference (5) Appendix A stated that an optimization model based on minimizing essentiality-weighted units short might be made available within the timeframes of UICP AVCAL and that the results of the RIM-AIR study would be delayed until testing of the optimization was completed. This report addresses both the impact of data inaccuracies on effectiveness and a simple optimization procedure developed specifically for RIM-AIR.

II. APPROACH

A. DATA. The set of data for this study consisted of all items applicable to the aircraft in the deckloads of the USS CONSTELLATION and assigned to NAS

Brunswick. The item data were extracted from the Allowance Requirements Registers (ARRs) used to construct the AVCALs that were generated for these activities in late 1980 and early 1981, respectively. The specific Type/Model/Series aircraft supported by each activity are shown in TABLE I.

TABLE I
Type/Model/Series Aircraft

USS CONSTELLATION Aircraft		NAS BRUNSWICK Aircraft
F14A A7E A6E KA6D EA6B	RF14A E2C SH3H S3A C1A	P3A P3B P3C UH1N

A total of 44,099 candidate items were extracted from the appropriate Section B, BN, R and X ARRs for the USS CONSTELLATION. The candidates were segregated into two main categories: consumables and repairables. The Repair Code (the fourth position of the Source Maintenance and Recoverability (SM&R) Code) was used to distinguish between the two categories. There were 34,852 candidate items with a Repair Code equal to B or Z. These items were considered to be consumables. The remaining 9,247 candidate items were considered to be repairables.

Similarly, a total of 13,389 candidates were extracted for NAS Brunswick. There were 3,474 candidate items with a repair SM&R code other than B or Z that were considered to be repairables. The remaining items were dropped since RIM-AIR is not being considered for consumable items at NASs where these requirements will continue to be determined using VOSL.

The item characteristics needed for RIM-AIR include the Rotatable Pool Factor (RPF), Maintenance Replacement Factor (MRF), Turnaround Time (TAT), and unit price. The RPF is the repair rate at the intermediate level of maintenance. The MRF is the attrition rate at the organizational and intermediate levels of maintenance. The TAT is the time it takes to remove a failed component at the organizational level of maintenance and repair it at the intermediate level. Data elements containing these item characteristics may be found in the ARRs and are Data Element Numbers (DENs) F001A (RPF), F001 (MRF) and F010E (TAT). These DENs were extracted for the candidate items by ASO for use in this study. The values found in these DENs as well as the unit price were screened to eliminate candidate items that were suspected of containing erroneous data that would distort the results of the study. A total of 454 candidates were deleted from the USS CONSTELLATION data base. Thirty-one repairable candidates were deleted from NAS Brunswick data base. TABLE II stratifies statistics on the number of candidates extracted from the ARRs, deletions and the net number of candidates used in the study by cog. Details of the criteria used in the screening process are contained in Appendix B.

TABLE II

Items Deleted by Screening

	USS CONSTELLATION	NAS BRUNSWICK
Total AAR Candidates	44,099	3,474
Total Candidates Deleted	454	31
Study Candidates	43,645	3,443
Repairable ARR Candidates	9,246	3,474
Total Repairables Deleted	61	31
Study Repairables	9,185	3,443
2R/8R Candidates	6,493	2,112
2R Deleted	50	26
Study 2R/8R	6,443	2,086
1R Candidates	2,069	621
1R Deleted	0	1
Study 1R	2,069	620
Consumable AAR Candidates	34,853	N/A
Total Consumables Deleted	393	N/A
Study Consumables	34,460	N/A
1R Candidates	6,952	N/A
1R Deleted	34	N/A
Study 1R	6,918	N/A
9 Cog Candidates	27,797	N/A
9 Cog Deleted	358	N/A
Study 9 Cog	27,439	N/A

The 61 repairable candidates deleted from the USS CONSTELLATION data base accounted for 31% of the total wartime quarterly removal forecast for all extracted USS CONSTELLATION repairable candidates. Fifty-three of the deleted repairables were on the AVCAL produced by ASO for the USS CONSTELLATION. The total dollar value of the AVCAL requirements for these items was $6.1M. The 393 consumables deleted accounted for 68% of the wartime quarterly removal forecast for all extracted consumable candidates. Thiry-seven of the deleted consumables had predicted quarterly removals in excess of 1,000 units. These items alone accounted for 39% of the quarterly removals for all consumable candidates. Three hundred eighty four of the deleted consumables were on the USS CONSTELLATION AVCAL. The total dollar value of the AVCAL requirements for these items was $204K. The 31 repairable candidates deleted from the NAS Brunswick data base accounted for 36% of the quarterly peacetime removal forecast for all extracted NAS Brunswick repairable candidates. One of these items had predicted quarterly removals in excess of 1,000 units and accounted for 17% of the quarterly removal forecast for all NAS Brunswick repairable candidates. Eighteen of the deleted repairables were on the ASO AVCAL with a total dollar value of $983K.

The RIM-AIR model requires data on order and ship time. Average order and ship times were computed for various cog groups as shown in TABLE III. All candidates within a cog group where assigned the average order and ship time.

TABLE III

Observed OSTs in Days

Cogs	USS CONSTELLATION	NAS BRUNSWICK
2R/8R	62.8	39.9
1R	51.9	31.8
All 9 Cog	51.9	26.9
Others	68.2	48.3

The order and ship times shown in TABLE III represent the total time from the date of the requisition to the receipt date. This includes the time an item may have been backordered at the Inventory Control Point (ICP). The data used to compute order and ship times for the USS CONSTELLATION came from the Requisition Response Time Management Information System (RRTMIS)/Performance Analysis of Response Time Segments (PARTS) report. Four quarters of calendar year 1980 data were compiled. Only requistions submitted and received while the ship was deployed were considered. The data used to compute order and ship times for NAS Brunswick came from the Uniform Automated Data Processing System

(UADPS) Level II Leadtime Process. Three quarters of data from 1980 and 1981 were compiled.

Benchmark requirement quantities were computed from the candidate data using the stockage criteria currently applied by ASO. USS CONSTELLATION requirements were computed to support a wartime flying hour program provided by ASO. NAS Brunswick requirements are only designed to support peacetime operations and were computed using a peacetime flying hour program provided by ASO. The benchmark requirements roughly equate to the gross AVCAL generated by ASO from the raw ARR data. The difference between the benchmark and the gross AVCAL is that the benchmark requirements were computed directly from the item characteristics found in the AARs whereas the ASO gross AVCAL is a compilation of precomputed ARR quantities. The benchmark for the USS CONSTELLATION was computed with and without the additional 2R/8R OST level that ASO will start adding to the AVCAL in the summer of 1983. The benchmark served as a point of comparison for the alternative versions of RIM-AIR examined in this study. The benchmark was also compared to the final AVCAL requirements produced by ASO for the two study activities.

B. ALTERNATIVE RANGE CRITERIA. Current requirement computations develop separate attrition and local repair cycle asset quantities. Separate range criteria exist to determine whether an item will be stocked for attrition and/or local repair cycle asset support. Attrition support is provided to items with predicted quarterly attrition demand above an established threshold. The threshold is varied according to the unit price of an item. Items with a unit price less than $5,000 are stocked if the predicted quarterly demand is .34 or more. This equates to an average of one unit attrited every nine months. Items costing $5,000 or more must have a predicted quarterly demand of .5 or more. This equates to one unit attrited every six months on the average.

There is one exception to this procedure. Items stocked for local repair asset support may only be stocked for attrition support if the predicted quarterly demand is one or more.

The decision to provide local repair cycle asset support is based on the predicted number of repair demands during the average Intermediate Maintenance Activity (IMA) TAT. Repair demands during the TAT represent the average number of units undergoing repair and is equal to the RIM-AIR repair cycle level. When this repair cycle level is .11 or greater, the item is stocked to a depth that gives 90% protection. The .11 cutoff is the point at which a quantity of zero no longer provides 90% protection. That is, items with a repair cycle of .11 or less don't require stockage because a stock quantity of zero satisfies the depth criteria. Thus, the range is really determined by the depth and nonstocked items are those computing to a depth of zero.

The current range criteria were examined in conjunction with RIM-AIR. This was done primarily to establish a range benchmark for comparison to other methods. The undesirability of splitting demand into pieces was established in reference (1) of Appendix A. The logical solution to the problem of split demand is to combine the demand prior to applying the range criteria. Since there are currently two approaches to selecting range, both were examined in this study in conjunction with the RIM-AIR depth model. In applying a demand threshold, the demand was not split into parts. The total projected number of removals was compared to a specified threshold parameter to determine if an item would be stocked. Similarly, RIM-AIR computes only one quantity that represents the total requirement to support both attrition and repair demands. Thus, when the range was determined by the depth computation, the item was stocked when the total requirement was one or more.

In addition to the two approaches to range selection discussed above, COMNAVSUPSYSCOM proposed using the concept of an Accommodation Index. The Accommodation Index is based on the gross and net supply effectiveness goals for an activity. For example, the OPNAVINST 4441.12A goal for ships and MAGs is to satisfy 75% of all demands and 85% of demands for stocked items. If sufficient depth is provided to meet the 85% net goal, then approximately 88.2% of all demands must be for stocked items if the 75% gross goal is to be achieved. The fact that the gross goal will be met may be seen by considering that if 85% of demands for stocked items are satisfied and demands for stocked items represent 88.2% of all demands, then 85% times 88.2%, or 75% of all demands will be satisfied. The Accommodation Index here is .882 and is derived by dividing the gross effectiveness goal by the net effectiveness goal. To meet the OPNAVINST 4441.12A goals for shore activities supporting aircraft the Accommodation Index is 65% divided by 85%, or approximately .765. The Accommodation Index is applied by arraying the candidates for stockage according to predicted quarterly removals. Candidates with the highest predicted removals are sequentially selected for stockage until the total predicted removals for stocked items equals or exceeds the product of the Accommodation Index and the total predicted removals for all candidates. In essence, the Accommodation Index approach is a kind of variable demand threshold where the demand threshold varies from activity to activity and is determined based on the list of candidates for stockage at an activity and the projected removals for each item.

C. <u>ALTERNATIVE SAFETY LEVEL CRITERIA</u>. The DOD instructions that apply to retail stockage computations do not specify how the safety level is to be computed. Current stockage criteria provide safety stock for the local repair cycle but not for attrition support which is computed as average attrition demand over the support period rounded at .5. There are two basic approaches to compute safety levels that were examined in this study. The first is to assign a given fixed level of protection which can be applied to all items. Currently local repair cycle quantities are provided 90% protection. The protection concept represents the probability that there are no backorders for an item at a random point in time. A further explanation of protection is provided in the next section entitled "Evaluation Criteria for RIM-AIR". The smallest integer quantity that provides the fixed protection on the repair cycle, OST, RDT and endurance delta levels is selected as the reorder point for each item.

The total requirement is the sum of the reorder point and operating level. The Operating Level (OL) for repairables is always one unit. For consumables, the operating level was computed as a Wilson EOQ:

$$OL = \sqrt{\frac{2*D*A}{I*C}}$$

where

D = annual peacetime attrition demand

A = order cost

I = holding cost rate

C = unit price

A Wilson EOQ was also computed for repairables when the range was determined by the depth computation. If the reorder point was zero, a repairable was still stocked in a quantity of one when the Wilson EOQ was one or more using .5 rounding.

The total safety level is obtained by subtracting the levels protected from the reorder point. The total safety level may be subdivided into peacetime, wartime, and endurance delta components. The detailed procedures for accomplishing this subdivision are contained in Appendix C.

The fixed protection approach outlined above has the advantage of simplicity. The total requirement for each item can be computed with a simple algorithm or even read from a table. Furthermore, each item's requirement is derived from its own characteristics and in no way depends on the characteristics of other items in the candidate file. Unfortunately, experience has shown that fixed protection can be very expensive. It is desirable to hold down the cost of an inventory without reducing the predicted level of performance for the inventory. This can be achieved by varying the protection afforded items according to individual item characteristics. Variable protection is the second approach to computing safety levels examined in this study. The definition of performance, or effectiveness, of an inventory applied in this study will be addressed in the next section titled "Evaluation Criteria". A discussion of the variable protection techniques examined in this study is presented below.

A simple, straightforward approach to variable protection is to directly compute an item's protection as a function of unit price, predicted removals and essentiality. As unit price increases, the level of affordable protection for an item decreases. As the number of predicted removals and the essentiality increase, the level of protection required to sustain performance increases. Mathematically, these relationships are embodied in the following formula for protection:

$$\text{Protection} = 1 - \frac{T*C}{E*D}$$

where

T = control parameter

C = unit price

E = essentiality

D = predicted removals

A control parameter (T) is included in the formula to serve as a mechanism for increasing or decreasing protection for all items. In general, the control parameter will be a value between zero and one. Decreasing the control parameter increases the protection given each item and hence increases the cost and predicted effectiveness of the requirements computed by this method. By altering the control value, a mix of requirements with a given total cost or predicted effectiveness can be found.

A more sophisticated approach to variable protection is to base requirements on the relative cost/effectiveness of the candidates. This technique is known as marginal analysis. The general procedure is simple. The cost/effectiveness of adding one additional unit of stock to each candidate is computed. The candidates are ranked according to the cost/effectiveness and one unit of stock is added for the most cost/effective item. The cost/effectiveness of adding the next unit for this item is then computed, its place in the ranking is determined and a unit of stock is again added for the next most cost/effective item. The process is continued until a total cost constraint or effectiveness target is reached. The advantage to this approach is that once a cost constraint is achieved, the inventory selected will provide the maximum amount of effectiveness achievable for that cost. Conversely, if an effectiveness target is selected, the process will select an inventory that achieves that effectiveness at minimal cost. The disadvantage to this approach is the fact that all candidate items and their relevant characteristics must be loaded into a computer before execution of the algorithm can begin. Computer capacity is thus a critical factor to the successful application of marginal analysis. Historically, the constraint on the number of items that could be loaded into the computer has limited the marginal analysis approach to problems involving a small range of candidates. Problems involving large numbers of candidates must be separated into a series of problems involving small packages of candidates. Even when a computer program is designed with what seems to be sufficient capacity, sooner or later a candidate package is encountered that exceeds that capacity and the program cannot be used for that package.

Fortunately, a mathematical technique exists that eliminates the computer capacity problem. The technique of Lagrange Multipliers in essence permits the stockage increments associated with a given item in the marginal analysis algorithm to be separately identified so that the stock level for the item can be determined based on that item's characteristics alone. The Lagrange Multiplier functions in a manner very similar to the control parameter used in the simple variable protection approach. The control parameter directly determined how much protection a particular item received. The Lagrange Multiplier indirectly determines this protection by deciding where the marginal analysis algorithm would stop if it were used. The lower the Lagrange Multiplier, the longer the algorithm would run, and hence, the greater the total cost and predicted effectiveness. A detailed explanation of the Lagrange Multiplier techique is presented in Appendix D. It should be noted that the simple variable protection approach is derived by applying the Lagrange Multiplier technique with a different effectiveness measure. This approach is used to compute requirements for load lists.

Both the simple variable protection and the Lagrange Multipler Optimization approaches allow direct computation of an item's requirements from the item's characteristics. However, this computation involves an unknown parameter, i.e., the control parameter or Lagrange Multiplier. Finding the right parameter, involves making a series of progressively educated guesses of the true value of the parameter. Requirements are computed for each item based on the current parameter estimates and total cost and predicted effectiveness statistics are accumulated. The relationships between cost and effectiveness and the unknown parameter can be established by plotting the results for each of the parameter estimates. A new set of refined parameter estimates can be made so as to produce results closer to the desired cost or effectiveness target. This iterative process can be repeated until a result is produced that is within tolerable limits of the target. The tolerable limits must be determined by the user. Experience in this study indicates that two or three iterations are usually needed to achieve the desired objective.

Because the simple variable protection and the Lagrange Multiplier Optimization approaches to variable protection both require estimating unknown parameters, neither is any easier to apply in practice than the other. Both require user involvement that is absent in the simpler fixed protection approach. However, the potential cost savings far outweigh the inconvenience. Both approaches were examined in this study. The optimization guarantees the highest effectiveness for the lowest cost if the item characteristics used in the computations are accurate. Although the protection given an item based on its own characteristics (which in the optimization are expanded to include TAT, OST, and RDT), that requirement can be affected by changes in the characteristics of other items. This means that theoretically all requirements should be reoptimized whenever any item characteristics change. Obviously, this is not very practical. Procedures for dealing with data base changes when an optimization is used are discussed in the Recommendation Section. This problem also exists with the simple variable protection approach because of the control parameter.

Both the simple variable protection and optimization approaches examined in this study are capable of having demand weighted with item essentiality. Currently, there is no readily available essentiality code that relates an item to it's impact on the mission of the weapons system. Efforts are underway to establish such codes for application in the future. A placeholder has therefore been put into the RIM-AIR computations to allow these codes to be applied once they become available.

D. EVALUATION CRITERIA. Three statistics were used to evaluate the alternative range and safety level criteria examined in this study: (1) range, (2) dollar value, and (3) supply effectiveness. Range refers to the total number of line items stocked by the range criteria. Dollar value is the total cost obtained by summing the product of the requirement quantity and unit price over all items stocked. Supply effectiveness is the percentage of demands for material that can be satisfied immediately from on-hand stock without waiting for the item to be repaired or requisitioned from an external source of supply. The supply effectiveness presented in this study was derived from an analytical model of the repair and requisitioning processes at the study activities. The analytical model predicts steady state supply effectiveness based on the charactersitics of the candidate items. Steady state supply effectiveness is that which would be reached once the repair and requisition processes were operating for an extended period of time. The steady state supply effectiveness statistic was selected for two reasons. First, steady state supply effectiveness is easy to compute. This is important because the capability to perform manual computations must exist. Second, the completeness and accuracy of the data required to perform computations is not good enough to justify using a more sophisticated performance measure at this time. Nonsteady state measures require specifying item characteristics as a function of time and this detailed scenario data does not currently exist in the production environment. Performance measures that address aircraft availability require indenture structures that have historically caused major data processing problems for computer models attempting to use them. Efforts are underway to identify and correct data base deficiencies. Reference (6) Appendix A delineates a long term operation analysis/research project at FMSO to develop a readiness oriented requirements model. However, it is anticipated that the steady state supply effectiveness measure will remain the only practicable means of predicting performance of a production inventory in the near future. A discussion of the steady state supply effectiveness measure used in this study is presented below. A detailed discussion of the mathematical background behind this measure may be found in Appendix D.

The steady state supply effectiveness used in this study is derived by viewing the repair and requisitioning processes at an activity as a queuing processes. Equipment failures generate arrivals. The RPF along with installed population and projected flying hours are used to determine the arrival rate for the IMA repair process. The MRF is similarly used to determine an arrival rate for the requisitioning process. The average time an item spends in the repair process is the IMA turnaround time. The average time an item spends in the requisitioning process is the peacetime order and ship time. Under wartime conditions, it was assumed that the order and ship time would increase by an amount equal to the resupply delay time. The average number of items in a queuing process equals the product of the average arrival rate and the average time spent in the process. Mean repair and requisition pipeline quantities were computed in this manner using peacetime and wartime flying hour projections.

The total mean pipeline is the sum of the mean repair and requisition pipelines.

A distribution of probabilities on the number of units in the repair or requisition queue can be postulated. In this study, a Poisson distribution was used. The mean of this distribution was set to the total mean pipeline discussed above. If no stock is carried at an activity, this distribution provides the probability that a given number of expeditious repair actions and/or direct turnover requisition exist at a random point in time. When stock is carried, these entities exist only when the number of units in the total pipeline exceeds the stock quantity. The probability that no backorders exist is the protection provided by the stock levels. Protection is the probability that the total pipeline is less than or equal to the stock quantity. Another probability of interest is the probability that a demand, which is assumed to occur on a one-for-one basis, can be satisfied by immediately issuing a unit from on-hand stock. This probability is known as a Fill Rate. The Fill Rate equals the probability that at least one RFI unit is available to issue. This in turn is the probability that the total pipeline is less than the stock quantity. Thus, the difference between protection and the Fill Rate is the probability that the total pipeline exactly equals the stock quantity. When this is true, there are no backorders but should a demand occur it would be backordered.

The expected number of satisfied demands over any period of time in steady state can be found by multiplying the Fill Rate by the expected number of demands. When essentiality becomes available, it will be used to weight the individual demands. The satisfied demands can be accumulated across items along with total expected demand. The expected supply effectiveness equals the accumulated units satisfied divided by the accumulated units of demand. Since demand is expressed in units, the supply effectiveness is unit effectiveness vice requisition effectiveness. Both gross and net supply effectiveness were computed this way. Gross effectiveness is the percentage of all demands satisfied. Net effectiveness is the percentage of demands for stocked items satisfied.

If supply effectiveness is predicted using the same item characteristics that were used to determine requirements then it is implicitly assumed that the item characteristics were accurate. The validity of this assumption is certainly questionable. In reality, the item characteristics used to compute requirements are forecasts. The reality that determines effectiveness inevitably differs from the forecast. The accuracy of the forecasting can impact the real-world performance of an inventory as much as the computational model used to generate requirements. Furthermore, the performance of all computational models are not necessarily impacted equally. Therefore, the accuracy of the data which will be input to a computational model should be considered when examining the relative merits of alternative techniques.

Two forms of data accuracy were addressed in this study: (1) the completeness of the candidate file constructed from the ARR, and (2) the accuracy of the item characteristics found in the ARR. The impact of demands for noncandidate items was determined as follows. Material issue transactions were extracted from the Navy Maintenance Material Management (3M) system. Data from all of calendar year 1981 were extracted from the USS CONSTELLATION while a July to December 1981 timeframe was used for NAS Brunswick. The data were compared by stock number to the ARR candidates. Material issues were coded as relating to either a candidate or noncandidate item. The ratio of total items demanded to candidate items demanded was computed for various cog groups. These ratios are displayed in TABLE IV. These ratios were used to factor up the gross expected demand forecast from the candidate item removal rate. The removal rate equals the RPF plus MRF. Net demand was not factored up because it only involves stocked items. There is no net demand for noncandidate items. The factored demand quantities were accumulated across items and used in the gross supply effectiveness computation.

TABLE IV

Gross Demand Factors

	USS CONSTELLATION	NAS BRUNSWICK
2R/8R	1.33	1.66
1R Repairables	1.17	1.78
1R Consumables	2.32	1.96
9 Cog	3.06	3.46
Others	1.00	1.00

The impact of using imperfect forecasts of item characteristics to compute requirements was assessed by treating the total mean pipeline computed from the forecasted characteristics as a random variable. That is, it was assumed that the "real" total mean pipeline was distributed somewhere around the known forecasted mean pipeline. A normal probability function with a mean equal to the known forecast and a variance (described below) was used to generate a sample of "real" total mean pipeline values. Each generated mean in the sample resulted in a different level of predicted units satisfied for an item given a fixed stockage quantity. If the generated mean pipeline is less than the forecast, the number of units satisifed will be greater than that which would be derived from the forecast. If the generated mean pipeline is greater, the number of units satisfied will be less. Using the normal distribution, theoretically half of the generated means will be less and half greater than the forecast of the mean. Generated mean pipeline values greater than the forecast have more of an impact on effectiveness than values less than the forecast; the average supply effectiveness, therefore, is less than that predicted with the forecast used to compute requirements. The difference increases as the variance of the normal distribution increases.

The variance of the normal distribution discussed above measures the accuracy of the item forecasts. The variance was determined by multiplying the forecasted total mean pipeline by a variance to mean ratio which was set so that the predicted benchmark (without the added OST level) supply effectiveness was close to that actually experienced by the activities. This procedure understates the variance to mean ratio because the performance observed at the activities is that of the final net ASO AVCAL. On the other hand, the benchmark approximates the gross AVCAL and, hence, would experience diminished performance. Because the difference in real-world performance between the gross and final net AVCALs is not known, the variance to mean ratio that reproduced the higher level of final net AVCAL performance had to suffice as a conservative estimate. Such a conservative estimate overstates predicted supply effectiveness although the magnitude is unknown. Variance to mean ratios of .5 for repairables and 20.0 for consumables were derived in this manner for the USS CONSTELLATION. Unfortunately, the conservative approach proved inadequate for NAS Brunswick where the predicted supply effectiveness of the benchmark was less than that observed in the real-world even if the forecasting was assumed to be perfect (i.e., variance to mean ratio equal to zero). A minimal variance to mean ratio of .1 was used for NAS Brunswick although the true value is undoubtedly higher. Thus, the predicted supply effectiveness for NAS Brunswick is probably overstated more than that shown for the USS CONSTELLATION.

III. FINDINGS

A. <u>DIRECT COMPUTATION BENCHMARKS VERSUS ASOs AVCALs</u>. The benchmark requirements used in this study were directly computed from the ARR candidate data. That is, the MRFs, RPFs and TATs for the candidate items extracted from the appropriate ARRs were used to compute attrition and local repair cycle asset quantities for each item. These two quantities were computed using the current OPNAVINST 4441.12A range and depth criteria and added to obtain the total requirement. The result should approximate the gross AVCAL ASO constructs using ARR data. The difference between the direct compute benchmark and the ASO gross AVCAL is that ASO extracts precomputed requirement quantities whereas the benchmark was computed from the item characteristics. The precomputed requirements found in an ARR will not always agree with the item characteristics in the same ARR. ASO refines the gross AVCAL by subjecting it to a stringent quality review process during which the gross AVCAL requirement may be changed. The result of this process is the final net AVCAL.

The range and dollar value of the direct compute benchmark and final ASO AVCAL requirements are displayed in TABLEs V and VI stratified by relevant cog groups. As shown in TABLE V, the total dollar value of the ASO AVCAL requirements are more than triple the total dollar value of the benchmark requirements for both activities. Furthermore, the range of items stocked on the ASO USS CONSTELLATION AVCAL exceeds the range stocked by the benchmark by 1,860 items. While the NAS Brunswick benchmark range appears to exceed the ASO AVCAL range, it includes 553 9 cog items coded as repairables based on the SM&R code. If these items are eliminated, the ASO AVCAL is seen to contain 364 more items. TABLE VI shows that the same situation exists for consumables although to a lesser degree.

TABLE V

ASO Repairable Requirements vs. Direct Compute Benchmark

	USS CONSTELLATION				NAS Brunswick			
	ASO AVCAL		Benchmark		ASO AVCAL		Benchmark	
	Range	$Value	Range	$Value	Range	$Value	Range	$Value
Total Repairable	5,544	69.4M	3,684	22.2M	1,346	10.5M	1,535*	3.1M
2R/8R	4,129	67.3M	2,547	21.8M	1,090	10.1M	806	2.9M
2R CLAMP	2,349	46.1M	1,357	12.7M	385	4.7M	302	1.4M
1R	975	2.1M	775	1.4M	256	0.4M	176	0.2M

*NOTE: Includes 553 9 cog repairables not on ASO AVCAL.

TABLE VI

ASO Consumable Requirements vs. Direct Compute Benchmark

	USS CONSTELLATION			
	ASO AVCAL		Benchmark	
	Range	$Value	Range	$Value
Total Consumables	21,385	4.3M	19,538	3.4M
1R	4,224	3.1M	4,274	2.4M
9 cog	17,106	1.2M	15,232	0.9M

The final net AVCAL can be expected to contain more material than the gross AVCAL because the tendency is to add rather than delete material during the quality review. However, when preliminary results of this study were presented to ASO representatives, they stated that the magnitude of the difference between the ASO AVCAL and the benchmark was greater than would be expected between the final net and gross AVCALs. An attempt was made to find the cause of this discrepancy. A sample of 100 CLAMP repairables was drawn from the data base for each activity. The sample data included the raw item data used in the benchmark requirements computations and the ASO AVCAL quantities. The sample data were provided to ASO for manual review. ASO concluded that the RPFs, MRFs and TATs in the sample data were smaller than those actually used by ASO to determine the AVCAL requirements. The cause of this raw data discrepancy could not be determined.

The results of the ASO manual review of the sample data indicate that the requirements computed from the ARR data base are understated due to deflated item characteristics. This means that the statistics contained in this report cannot be interpreted as absolute results. The range and dollar value of any of the alternatives examined would increase if that alternative were implemented. However, the deflated item characteristics should not affect the relative comparisons made between alternatives. The range and safety level criteria recommendations as a result of this analysis are therefore valid.

B. REPAIRABLES ANALYSIS.

1. Fixed Protection. TABLEs VII and VIII show the impact of adding various stock levels to the benchmark requirement until the RIM-AIR requirement is achieved. The current range criteria were used to select items for stockage and the safety level was computed to yield 90% fixed protection. The 90% protection level was selected because the benchmark local repair cycle asset quantities are protected to 90%. Statistics are also shown for RIM-AIR requirements computed with 85% and 80% protection. The statistics shown are range, dollar value of the total requirement as well as various component levels and supply effectiveness. Three supply effectiveness measures are included for the USS CONSTELLATION. The first is based on peacetime flying hours, the second and third wartime flying hours. The difference between the two wartime measures is that the first assumes there is no RDT, i.e., the time it will take to requisition material in war will be the peacetime order and ship time. The second measure assumes an RDT of 30 days is added to the peacetime order and ship time in wartime. Only peacetime effectiveness is

shown for NAS Brunswick because the benchmark requirements are computed to support peacetime operations. The maximum effectiveness that can be achieved with the current range rule is shown at the bottom of each table.

TABLE VII

Impact of RIM-AIR Under Fixed Protection on USS CONSTELLATION Repairables

	Range	Total $ Value	Wartime Repair Cycle+OST+RDT $ Value	Safety Level $ Value	OL $ Value	Protected End Δ $ Value	Peacetime Effectiveness		Wartime Effec. w/o RDT		Wartime Effec. with RDT	
							Gross	Net	Gross	Net	Gross	Net
Benchmark	3,680	22.2M	18.0M	4.2M	0	0	64	87	57	77	39	52
Benchmark with 2R/8R OST Levels	3,680	25.1M	18.9M	6.2M	0	0	66	89	60	81	44	60
Wartime pipeline w/90% Protection	3,680	35.7M	18.9M	16.8M	0	0	68	93	65	87	53	71
Protected pipeline + OL	3,680	46.3M	18.9M	16.8M	10.6M	0	72	98	71	95	61	83
Protected pipeline + End Δ Protected to 90%	3,680	47.2M	18.9M	16.5M	0	11.8M	70	95	68	91	64	87
RIM-AIR w/90% Protection	3,680	57.8M	18.9M	16.5M	10.6M	11.8M	73	99	72	97	70	94
RIM-AIR w/85% Protection	3,680	53.0M	18.8M	12.4M	10.6M	11.2M	72	98	71	95	68	91
RIM-AIR w/80% Protection	3,680	49.5M	18.8M	9.5M	10.6M	10.6M	71	97	70	94	66	89
Maximum effectiveness with current range rule							74	100	74	100	74	100

TABLE VIII

Impact of RIM-AIR Under Fixed Protection on NAS Brunswick Repairables

	Range	Total $ Value	Peacetime Repair Cycle+OST $ Value	Safety Level $ Value	OL $ Value	Protected End Δ $ Value	Peacetime Effectiveness	
							Gross	Net
Benchmark	1,535	3.1M	1.7M	1.4M	0	0	40	55
Peacetime Pipeline w/90% Protection	1,535	4.4M	2.0M	2.4M	0	0	60	83
Protected Pipeline + OL	1,535	6.5M	2.0M	2.4M	2.1M	0	67	92
Protected Pipeline + End Δ Protected to 90%	1,535	6.5M	2.0M	2.3M	0	2.2M	69	96
RIM-AIR w/90% Protection	1,535	8.6M	2.0M	2.3M	2.1M	2.2M	71	99
RIM-AIR w/85% Protection	1,535	7.8M	2.0M	1.7M	2.1M	2.0M	71	98
RIM-AIR w/80% Protection	1,535	7.3M	2.0M	1.2M	2.1M	2.0M	70	97
Maximum effectiveness with current range rule							72	100

This maximum is derived by assuming that all demands for stocked items are satisfied, i.e., 100% net effectiveness.

In order to show the transition from the benchmark to RIM-AIR, it was necessary to allocate the benchmark quantities against the RIM-AIR requirements. The local repair cycle asset quantities were broken down into a repair cycle level and safety level. The 90 day attrition quantities were segmented into OST and RDT levels. The OST levels were based on the order and ship time data observed at the activities as discussed in the Approach Section. The RDT was set equal to 30 days, the same period used in the second wartime effectiveness measure. If there was stock left over in the attrition quantity after building OST and RDT levels for an item, it was applied against the safety level requirement. If the attrition quantity was insufficient to fill the OST and RDT levels, it was first allocated to OST, then to RDT until it was exhausted.

The impact of adding the 2R/8R cog OST levels for the USS CONSTELLATION is shown in TABLE VII. The OST levels were constrained to 12 days for CLAMP items and 30 days for all other 2R/8R items. The constrained OST level was added to the 90 day attrition level and the total segmented into observed OST and RDT levels as described above. Therefore, the effect of adding the 2R/8R OST levels was primarily to increase the safety level since the 90 day attrition quantity was sufficient to cover the OST and RDT levels for most items.

The greatest payoff in effectiveness resulted from fully protecting the basic pipeline levels. The benchmark quantities provided little safety level. The 2R/8R OST levels accounted for less than a quarter of the cost of full protection. However, this modest investment produced an increase in effectiveness equal to more than a third of that achieved by full protection. As the operating level and endurance delta were added, the cost per percentage point increase in gross wartime effectiveness increased for the USS CONSTELLATION. The same is true with gross peacetime effectiveness for NAS Brunswick. This trend of diminishing returns can be seen acting in reverse as protection is lowered. Each decrease of 5% protection results in a drop of one to two percentage points of gross effectiveness for the USS CONSTELLATION. The cost reduction associated with dropping the protection from 90% to 85%, however, is greater than that produced when the protection is further reduced to 80%. The same trend occurs for NAS Brunswick. A more detailed analysis of the individual levels is presented below.

The first step in the transition was to fully protect the OST and RDT levels along with the repair cycle level to 90%. As can be seen from the tables, the basic repair cycle, OST and RDT level requirements are almost completely satisfied by the benchmark quantities. However, there was little left over for safety level. The impact of the safety level deficiency is seen to be between eight and 14 percentage points of gross wartime effectiveness for the USS CONSTELLATION (depending on whether the RDT is considered) and 20 percentage points gross peacetime effectiveness for NAS Brunswick. The cost increase in Total Dollar Value to fill the basic levels and provide a 90% safety level was $13.5M for the USS CONSTELLATION and $1.3M for NAS Brunswick. The 2R/8R OST levels are seen to provide $2.9M of the deficiency for the USS CONSTELLATION with a payback of three to five percentage points of gross wartime effectiveness.

The next step in the transition was to add the operating level (OL) and endurance delta level (End Δ). These levels are shown as they were added individually to the protected wartime pipeline requirement. The endurance delta level for the USS CONSTELLATION was computed assuming a 90 day wartime endurance period. The NAS Brunswick endurance delta is based on a 30 day peacetime endurance period. The endurance delta level is protected to 90% and the cost of the protected endurance delta displayed in the tables includes the resulting safety level. The USS CONSTELLATION operating level costs $900K less than the endurance delta yet results in a greater increase in effectiveness in peacetime and wartime where there is no RDT. When the RDT is considered in the effectiveness measure, the endurance delta provides greater predicted effectiveness in return for the added cost. The NAS Brunswick operating and endurance delta levels both cost the same. The endurance delta level, however, produces two percentage points additional gross effectiveness and four percentage points additional net effectiveness.

The transition to RIM-AIR is completed by adding both the operating level and the protected endurance delta to the protected repair cycle, OST and RDT levels. The total USS CONSTELLATION RIM-AIR requirement costs $22.1M more than the protected pipelines. This is approximately double the cost of adding the operating level alone yet the effectiveness of the total RIM-AIR requirement is only one to two percentage points greater than that produced by adding the operating level in peacetime and wartime if there is no RDT. The cost of stocking both levels pays off when the RDT is considered in the effectiveness measure where a six to nine percentage point increase in gross effectiveness over that achieved with either level individually is observed. The total NAS Brunswick RIM-AIR requirement costs twice as much as the protected repair and OST pipelines. The increase in cost is almost twice that of adding the endurance delta alone yet the increase in effectiveness is only two percentage points gross and three percentage points net.

The maximum gross supply effectiveness achieveable with the current range rule for the USS CONSTELLATION as shown in TABLE VII is 74%. This is one percentage point below the OPNAVINST 4441.12A supply effectiveness goal for ships/MAGs. To achieve the 74%, the net supply effectiveness must be 100% which is theoretically impossible. The gross effectiveness produced by RIM-AIR is 3 to 9 percentage points short of the goal depending on the protection level and type of wartime effectiveness. An in-depth analysis of the alternative range criteria discussed in the Approach Section is presented in Appendix E. This analysis shows that stocking items based on projected removals above a threshold produces the greatest gross supply effectiveness for a given cost with fixed protection. Accordingly, the removal threshold that yielded the OPNAVINST 4441.12A gross supply effectiveness goal of 75% for the USS CONSTELLATION when used in conjunction with RIM-AIR protected to 85% was found. The results indicate that the threshold that achieves the goal with both wartime supply effectiveness measures is one removal every four years. Range, dollar value and supply effectiveness statistics for this alternative for USS CONSTELLATION are presented in TABLE IX. Also shown is the maximum effectiveness that can be achieved with the universe of candidates extracted from the ARRs. These maximum values were determined by assuming that all demands for ARR candidates are satisfied. This means all ARR candidates would have to be stocked with sufficient depth to satisfy all candidate demands.

It can be seen from TABLE IX that it was necessary to almost double the range and increase cost by $14.9M to achieve the OPNAVINST 4441.12A effectiveness goals. The total cost to achieve the OPNAVINST 4441.12A goal is triple the benchmark cost. As stated in the Approach Section, fixed protection may be simple to use but it is expensive. Fortunately, the cost can be reduced by applying the variable protection techniques discussed in the Approach Section. A discussion of the impact of variable protection is provided in the next section of the report entitled "Variable Protection".

TABLE IX

Quarterly Removals Above Threshold Vs. Current Range Criteria for Repairables

USS CONSTELLATION	Range	Total $ Value	Peacetime/Wartime Repair Cycle+OST+(RDT) $ Value (See Note)	Safety Level $ Value	OL $ Value	Protected End Δ $ Value	Peacetime Effectiveness		Wartime Effectiveness w/o RDT		Wartime Effectiveness with RDT	
							Gross	Net	Gross	Net	Gross	Net
RIM-AIR w/current range criteria	3,680	53.0M	18.8M	12.4M	10.6M	11.2M	72	98	71	95	68	91
RIM-AIR w/items stocked if removed once every 4 yrs.	6,744	67.9M	20.5M	15.1M	19.3M	13.0M	79	98	78	96	75	92
Maximum effectiveness with ARR Candidate File							82	100	82	100	82	100
NAS Brunswick												
RIM-AIR w/current range criteria	1,535	7.8M	2.0M	1.7M	2.1M	2.0M	71	98				
RIM-AIR w/items stocked if removed once every 4 mos.	1,325	7.8M	2.0M	1.6M	2.1M	2.1M	71	98				
RIM-AIR w/items stocked if removed once every 6 mos.	1,556	9.0M	2.1M	1.9M	2.7M	2.3M	72	98				
Maximum effectiveness with ARR Candidate File							76	100				

NOTE: USS CONSTELLATION - Wartime Repair Cycle + OST + RDT
NAS Brunswick - Peacetime Repair Cycle + OST

The statistics in TABLE VIII show that the current range criteria produce gross effectiveness above the OPNAVINST 4441.12A goal of 65% for NAS Brunswick when used with 80-90% fixed protection. These effectiveness statistics are overstated because of the conservative estimate of the item characteristic variance used for NAS Brunswick. The problem of estimating the variance of item characteristics for NAS Brunswick is discussed in Section D of the Approach Section. An inventory with gross effectiveness closer to the 65% goal was produced by lowering protection to 50%. This, in essence, eliminated the safety level and resulted in a gross effectiveness of 66%. The effectiveness is held at this level by the endurance delta which serves as a substitute safety level. This means the self-support capability provided by the endurance delta is diminished and hence is not desirable. Another way to lower gross effectiveness to the goal is to lower the range. To reach 65%, the range must be reduced to an unrealistic level. This is not a reasonable alternative to lowering safety level. It was decided to keep the safety level for the remainder of the NAS Brunswick analysis. An attempt was made to keep the range within a few hundred items of the benchmark. While this means the cost of exactly satisfying the OPNAVINST 4441.12A is not shown for NAS Brunswick, the relative costs are probably more representative of what would result if RIM-AIR was implemented with any of the alternatives examined.

Although the current range criteria appear adequate based upon the statistics presented in TABLE VIII, the impact of using predicted removals above a threshold was still examined for NAS Brunswick. The results are displayed in TABLE IX. First, the threshold that produced a RIM-AIR inventory with the same cost as the benchmark range criteria with 85% protection was found. It turned out that a cost of $7.8M could be achieved if all items predicted to be removed at least once every four months were stocked. The range of items stocked under this new criteria decreased by over 200 items but effectiveness remained the same. The fact that the same level of effectiveness was maintained with fewer items indicates that the removal threshold criteria is stocking items with a larger forecasted removal rate. The removal threshold was lowered until a range approximately equal to the benchmark range was produced. The threshold required was one removal every six months. The cost to maintain the same range as the benchmark was $1.2M. Half the additional cost was in the operating level which indicates the items stocked by the removal threshold are more expensive than those stocked by the benchmark. This makes sense because the benchmark attrition thresholds are varied according to price. A lower threshold is applied to cheaper items. In applying the removal threshold, the threshold was held constant for all items. The additional investment produced by the removal threshold resulted in a one percentage point increase in gross effectiveness.

2. Variable Protection. A comparison between fixed protection and the simple variable protection and optimization approaches was made using the current range criteria and the alternative range criteria discussed in the Approach Section. An analysis of the impact of variable protection under the different range criteria is presented in Appendix F. The results of this analysis show that both variable protection approaches produce higher effectiveness for a given cost regardless of the range criteria. Surprisingly, the simple variable protection and optimization approaches produced the same level of effectiveness for a given cost when the range was not determined by the depth computation. This shows that the simple variable protection approach produces a good approximation of the optimal depth. When range was determined by the depth, the optimization generated higher gross effectiveness for a given cost. This was true for both activities.

The analysis in Appendix F shows that the simple variable protection approach does not produce as large a range as the optimization approach when range is determined by depth. The optimization model selected a greater range of items for both activities. The different range criteria were analyzed in conjunction with the optimization in Appendix E. The results of this analysis for the USS CONSTELLATION show that quarterly removals above a threshold and range determined by depth both produce inventories with the same predicted gross effectiveness for a given cost when depth is computed with the same Lagrange Multiplier. Both produced higher gross effectiveness for a given cost than the current range criteria for the USS CONSTELLATION. The same Lagrange Multiplier is used with each range rule so that the depth computation is constant and only the impact of the different range criteria is observed in the statistics.

For NAS Brunswick, the gross effectiveness resulting from a range determined by depth was one percentage point higher than that produced by quarterly removals above a threshold under conditions of equal cost and Lagrange Multiplier. The current range criteria and quarterly removals above a threshold both produced the same gross effectiveness for a given cost for NAS Brunswick.

Although the quarterly removals above a threshold and range by depth criteria produce inventories with almost the same gross effectiveness for a given cost, the specific items stocked by each are different. Appendix E shows that the total range generated by the range by depth criteria is over 1,000 items larger than that generated by quarterly removals above a threshold for the USS CONSTELLATION. The range by depth rule stocked over 700 more items for NAS Brunswick. Which range criteria is better for use with the optimization? Quarterly removals above a threshold has an inherent disadvantage. A threshold must be selected. Under fixed protection, the threshold that produced 75% gross effectiveness when protection was set at 85% for the USS CONSTELLATION was found to be one removal every four years. Different thresholds could also have been found for different levels of protection. The cost associated with these different combinations of range and depth could have been used to differentiate between the combinations. The combination that produced the 75% gross goal at least cost would have been best. Similarly, different combinations of range and depth could be produced with the optimization. Again, the combination that produced the OPNAVINST 4441.12A goal at least cost would be best. The threshold used with that combination would be the most desirable.

The procedure outlined above for finding a threshold would be cumbersome to apply. Yet simply assigning some arbitrary threshold value means spending more than necessary to achieve the OPNAVINST 4441.12A goal. Herein lies the advantage of the range by depth criteria. When used in conjunction with the optimization, it automatically selects the right combination of range and depth. The inventory produced is optimal in terms of range and depth. Intuitively, an optimized range would seem more likely to vary across successive requirement recomputations. Such churn in the items stocked from AVCAL to AVCAL is costly but could be minimized by the addition of a constraint on the optimized range as discussed in Appendix E.

The impact of applying the optimization to produce an inventory that meets the OPNAVINST 4441.12A supply effectiveness goals for the USS CONSTELLATION is shown in TABLE X. First, the cost is reduced $15.1M by optimizing depth while continuing to establish the range with the threshold of one removal every four years. Next, the cost is further reduced $3.3M by optimizing both range and depth. Overall, the optimization reduced the cost to achieve the OPNAVINST

4441.12A goals by 27%. It should be noted that the net effectiveness of the optimal inventory exceeds the 85% goal. No further cost reduction can be achieved by reducing net effectiveness. To do so would be to change the combination of range and depth selected by the optimization. An inventory with gross and net effectiveness exactly equal to the OPNAVINST 4441.12A goals would cost more. It is cheaper to meet the gross goal while exceeding the net goal.

TABLE X

Impact of Optimization on Repairables

USS CONSTELLATION	Range	Total $ Value	Peacetime/Wartime Repair Cycle+OST+(RDT) $ Value (See Note)	Safety Level $ Value	OL $ Value	Protected End Δ $ Value	Peacetime Effectiveness		Wartime Effec. w/o RDT		Wartime Effec. with RDT	
							Gross	Net	Gross	Net	Gross	Net
RIM-AIR w/items stocke if removed every 4 yrs.	6,744	67.9M	20.5M	15.1M	19.3M	13.0M	79	98	78	96	75	92
Optimized RIM-AIR w/items stocked if removed every 4 yrs.	6,744	52.8M	19.8M	5.7M	19.3M	8.0M	79	98	78	96	75	92
Optimized RIM-AIR w/range determined by depth	6,428	49.5M	19.8M	6.3M	15.4M	8.0M	79	98	78	96	75	93
<u>NAS Brunswick</u> RIM-AIR w/items stocke if removed once every 4 mos.	1,325	7.8M	2.0M	1.6M	2.1M	2.1M	71	98				
Optimized RIM-AIR w/items stocked if removed every 4 mos.	1,325	5.9M	1.9M	.6M	2.1M	1.3M	71	98				
Optimized RIM-AIR w/range determined by depth	1,819	5.4M	1.9M	.4M	1.8M	1.3M	71	97				

NOTE: USS CONSTELLATION - Wartime Repair Cycle + OST + RDT
NAS Brunswick - Peacetime Repair Cycle + OST

For NAS Brunswick, the optimization was used to reduce the cost of providing the effectiveness achieved with 85% fixed protection and quarterly removals above a threshold of one every four months shown in TABLE IX. The results, displayed in TABLE X, show that optimizing depth alone reduced the cost by $1.9M. Optimizing range and depth produced a further half a million dollar reduction.

C. CONSUMABLES ANALYSIS.

1. Fixed Protection. TABLE XI shows the impact of adding various stock levels to the USS CONSTELLATION benchmark requirement until the RIM-AIR requirement is achieved. The current range criteria were used to select items for stockage and the safety level was computed to yield 90% fixed protection as with the repairables analysis. Statistics are also shown for RIM-AIR requirements computed with 85% and 80% protection. The statistics shown are range and dollar value of the total requirement as well as various component levels and supply effectiveness. Three supply effectiveness measures are shown. The first is based on peacetime flying hours, the second and third wartime flying hours. The difference between the two wartime measures is that the first assumes there is no RDT, i.e., the time it takes to requisition material in war will be the peacetime order and ship time. The second measure assumes an RDT of 30 days is added to the peacetime order and ship time in wartime. The effectiveness statistics displayed with each measure are expressed as a range of possible values. As discussed in Appendix D, consumable effectiveness computations must consider the time between when a demand occurs and when a replacement is requisitioned. Repairables are requisitioned on a one for one basis and it is assumed that a requisition is placed immediately upon demand to either replace an issued unit or fill an outstanding requirement. Consumables, on the other hand, are requisitioned in

order quantities greater than one. If a demand is satisfied from on-hand stock, a requisition to replace it will not be submitted immediately. Only when the number of units issued is at least as large as the order quantity will a requisition to replace all the issued units be submitted. The time spent waiting to place a requisition generates a kind of prerequisition pipeline. This prerequisition pipeline is added to the requisition pipeline and the resulting total pipeline is used to compute fill rates. The fill rates are computed in a conservative manner so that the resulting effectiveness represents a lower bound. An upper bound on effectiveness is developed by assuming there is no such waiting time, i.e., consumables are requisitioned one for one. The true effectiveness lies somewhere in-between.

TABLE XI

Impact of RIM-AIR Under Fixed Protection on USS CONSTELLATION Consumables

	Range	Total $ Value	Wartime OST+RDT $ Value	Safety Level $ Value	OL $ Value	Protected End Δ $ Value	Peacetime Effectiveness		Wartime Effec. w/o RDT		Wartime Effec. with RDT	
							Gross	Net	Gross	Net	Gross	Net
Benchmark	19,538	3.4M	2.8M	.6M	0	0	4-22	11-67	3-15	8-45	2-7	5-22
Wartime pipeline w/90% Protection	19,538	4.9M	2.8M	2.1M	0	0	5-26	15-79	4-19	11-56	2-9	7-27
Protected pipeline + OL	19,538	7.7M	2.8M	2.1M	2.8M	0	30-33	92-98	29-32	88-95	27-29	81-89
Protected pipeline + End Δ protected to 90%	19,538	6.9M	2.8M	2.1M	0	2.0M	9-30	26-91	7-26	21-78	5-17	14-50
RIM-AIR w/90% Protection	19,538	9.7M	2.8M	2.1M	2.8M	2.0M	31-33	95-99	31-32	92-97	29-31	87-92
RIM-AIR w/85% Protection	19,538	9.1M	2.8M	1.7M	2.8M	1.8M	31-33	94-99	30-32	92-97	29-30	86-92
RIM-AIR w/80% Protection	19,538	8.6M	2.8M	1.2M	2.8M	1.8M	31-33	94-99	30-32	91-96	28-30	85-91
Maximum effectiveness with ARR Candidate File							34	100	34	100	34	100

The maximum effectiveness that can be achieved with the universe of ARR candidates is shown at the bottom of TABLE XI. These maximum values were determined by assuming that all demands for ARR candidates are satisfied. This means all ARR candidates would have to be stocked with sufficient depth to satisfy all candidate demands.

In order to show the transition from the benchmark to RIM-AIR, it was necessary to translate the benchmark quantities into the levels of stock utilized in RIM-AIR. The 90 day attrition quantity was segmented into OST and RDT levels. The OST levels were based on the order and ship time data observed at the activities as discussed in the Approach. The RDT was set equal to 30 days, the same period used in the second wartime effectiveness measure. If there was attrition stock left over after building OST and RDT levels for an item, it was considered safety level. If the 90 day attrition quantity was insufficient to fill the OST and RDT levels, it was first allocated to OST, then to RDT until it was exhausted.

The greatest payoff in effectiveness resulted from the addition of the operating level. Fully protecting the basic OST and RDT levels, which receive little protection from the benchmark quantities, and adding the endurance delta increased effectiveness to a lesser degree. A detailed analysis of the individual levels is presented below.

The first step in the transition was to fully protect the OST and RDT levels to 90%. As shown in TABLE XI, the basic OST and RDT levels are filled by the benchmark quantities but there is little left over for safety level. The impact of the safety level deficiency is seen to be two to four percentage points gross wartime effectiveness in the maximum case depending on whether the RDT is considered. The cost to provide a 90% safety level is $1.5M.

The next step in the transition was to add the operating level (OL) and endurance delta level (End Δ). These levels are shown being added individually to the protected wartime pipeline quantities. The endurance delta level was computed assuming a 90 day wartime endurance period. The endurance delta level is protected to 90% and the cost of the protected endurance delta displayed in TABLE XI includes the resulting safety level. The operating level adds $2.8M to cost of the protected wartime pipeline, the endurance delta $2.0M. The addition of the operating level results in higher effectiveness across the board. The minimum effectiveness associated with adding the operating level is at least as great as the maximum effectiveness associated with adding the endurance delta level. The minimum effectiveness statistic is particularly sensitive to the operating level. Adding the operating level increases the minimum gross effectiveness 25 percentage points with each measure. This sensitivity is due to the fact that the prerequisition pipeline considered in the minimum effectiveness is supported by the operating level. If an operating level is not included as part of the stock quantity the unsupported prerequisition pipeline degrades effectiveness.

The transition to RIM-AIR is completed by adding both the operating level and the protected endurance delta to the protected OST and RDT levels. The total RIM-AIR requirement costs $4.8M more than the protected pipeline. This is $2.0M (the cost of the endurance delta) more than the cost of adding the operating level alone. The added cost increases gross wartime effectiveness about two percentage points.

The peacetime and wartime gross effectiveness predicted for the total RIM-AIR requirement are far below the OPNAVINST 4441.12A goal of 75%. This shortfall is due to the large number of demands for noncandidate items. The maximum gross effectiveness achievable with the ARR candidate data is 34%.

Thus, no range criteria can stock enough items to meet the OPNAVINST 4441.12A goal. An analysis of the alternative range criteria discussed in the Approach Section is presented in Appendix E. For consumables, there is no difference between the current criteria and quarterly removals above a threshold. Both stock items based on predicted attrition demand above a threshold. The range criteria analyzed in Appendix E, therefore, consisted of the current criteria and the range by depth criteria. The Accommodation Index was also examined as a mechanism for establishing an attrition threshold.

The analysis shows that with 85% fixed protection, the range by depth criteria stocks more items for a given cost. Intuitively, the greater range should produce higher gross effectiveness. However, because the gross effectiveness of both alternatives was near the maximum possible with the ARR candidates, no difference in effectiveness was observed. Which range criteria then is best for consumables? The range determined by depth criteria is easier to apply. The range is automatically determined by the depth computation. However, as discussed in Appendix E, range by depth is driven by the operating level for low cost items and tends to stock nearly all low cost items with predicted peacetime demand greater than zero. The current criteria has the ability to differentiate between low cost items and is therefore preferable. The only requirement for using the current criteria is that a demand threshold be established. Until the consumable candidate data is improved, the establishment of a threshold will be a subjective decision process that considers the magnitude of the range associated with various threshold values.

2. Variable Protection. A comparison between fixed protection and the simple variable protection and optimization approaches was made using the current and range by depth criteria. The impact of the variable protection approaches is analyzed in Appendix F. This analysis fails to show any benefit

to the variable protection approaches for consumables. How is this possible? The large number of demands for noncandidates and high variance to mean ratio used to describe the accuracy of the candidate item characteristics negated the benefits of varying protection.

If the variable protection approaches are no more cost effective than fixed protection, the simplicity of the fixed protection approach makes it more desirable. Should the consumable data improve, the variable protection approaches should prove beneficial. Variable protection will become necessary when item essentiality coding is developed so that items deemed essential to the mission of a weapons system will be afforded greater protection.

IV. SUMMARY

A. <u>BACKGROUND</u>: RIM-AIR was proposed by COMNAVSUPSYSCOM to eliminate the dichotomy in policy established by OPNAVINST 4441.12A. This instruction provides material availability goals that cannot be achieved with the stockage criteria set forth in the same instruction. RIM-AIR was designed to comply with DODIs 4140.45, 4140.46, and 4140.47. RIM-AIR provides material to cover the repair and requisition pipelines that form in support of aircraft operations.

The RIM-AIR requirement consists of an operating level, repair cycle level, order and ship time level, resupply delay time level, endurance delta level and safety level. All but the endurance delta level are authorized by the DOD instructions listed above. The endurance delta level was included to assure a self-supporting capability for a prescribed period of time. The requirement for such a self-support capability is established in OPNAVINST 4441.12A.

Requirements for the initial outfitting of a weapon system are determined during the provisioning process. To be implemented in provisioning, RIM-AIR must be capable of complying with DODI 4140.42. RIM-AIR can easily be adapted to comply with this instruction by eliminating the safety level. The RIM-AIR model has been proposed for use in the UICP AVCAL system.

Only two distinctions need to be made in order to apply RIM-AIR to consumables. First, the operating level may be greater than one for consumables. Secondly, consumables do not require a repair cycle level. There is a need for a consumable requirement computation for ships/MAGs. Consumable retail requirements for Naval Air Stations are computed under Variable Operating and Safety Level (VOSL) procedures.

B. APPROACH. RIM-AIR as developed by COMNAVSUPSYSCOM is a depth model. The purpose of this study is to evaluate the cost/effectiveness of alternative range and safety level criteria. The evaluation criteria used is the percentage of demands for material that can be satisfied immediately from on-hand stock; i.e., supply effectiveness. The analytical model used predicts supply effectiveness based on the demand characteristics of the candidate items. The impact of data integrity on supply effectiveness was considered. The completeness of the candidate file and the accuracy of the candidate item characteristics used in the computations were considered in predicting effectiveness. The method used to estimate the accuracy of item characteristics was such that the predicted effectiveness is probably overstated. However, relative comparisons are still valid.

The data base for this study consisted of all items applicable to the aircraft in the deckload of the USS CONSTELLATION and assigned to NAS Brunswick. The item data were extracted from the ARRs used to construct the AVCALs that were produced for those activities in late 1980 and early 1981, respectively. The items were segregated into two main categories: consumables and repairables. The item characteristics needed for RIM-AIR were screened to eliminate items that were suspected of containing erroneous data that would distort the results of the study. Order and ship time data for the USS CONSTELLATION were extracted from the RRTMIS/PARTS report. Order and ship time data for NAS Brunswick came from the UADPS Level II Leadtime Process.

Benchmark requirements were computed from the candidate item data using the stockage criteria currently applied by ASO. These benchmark requirements roughly equate to the gross AVCAL computed by ASO from raw ARR data. The range and dollar value of the benchmark and ASO final AVCAL were compared. The range and dollar value of the ASO final AVCAL exceeded the benchmark by a magnitude greater than would be expected between the final and gross AVCALs. ASO concluded that the item characteristics used to compute the benchmark were deflated compared to those used to compute the actual AVCAL requirements. Thus, the requirements computed in this study using the ARR data base are understated and the range and dollar value statistics based on these requirements cannot be interpreted as absolute results. The range and dollar value of any of the alternatives examined would increase over the study values if the alternative were implemented. As with the effectiveness, however, relative comparisons between alternatives are still valid.

The alternative safety level criteria examined in this study consisted of fixed protection, simple variable protection and an optimization procedure. Fixed protection means assigning the same level of protection to each item. Variable protection involved computing protection for an item as a function of unit price, predicted removals, and a control parameter. The optimization procedure produces a mix of item requirements that maximize effectiveness for a given cost target or, conversely, minimize cost for a given effectiveness target. Protection is varied implicitly and depends on the relative cost/effectiveness of the candidate items.

The alternative range criteria examined in this study consisted of the current criteria, range determined by the depth computation and quarterly removals above a threshold. Currently, separate range criteria are used to determine whether an item will be stocked for attrition or local repair cycle asset support. The sum of attrition and local repair asset quantities determines the total requirement. As applied in the study, range determined by depth stocked an item when the total requirement was one or more. Quarterly removals combined attrition and repair demands and compares the total to a threshold to determine stockage.

C. REPAIRABLES ANALYSIS. The benchmark requirements almost completely filled the repair, order and ship time and resupply delay time levels for both study activities. However, there was little left over for a safety level. The cost to provide a full 90% safety level was $13.5M for the USS CONSTELLATION and $1.3M for NAS Brunswick. The impact of the safety level deficiency was between 8 and 14 percentage points gross wartime effectiveness depending on whether the resupply delay time is considered for the USS CONSTELLATION and 20 percentage points gross peacetime effectiveness for NAS Brunswick. The 2R/8R OST level initiative increased the USS CONSTELLATION gross wartime effectiveness three to five percentage points and cost $2.9M.

Fully protecting the basic pipeline levels provided the greatest increase in effectiveness. Further addition of the operating and endurance delta levels also increased effectiveness but the cost per percentage point increase went up. The total RIM-AIR requirement provided 66-72% gross and 89-97% net wartime effectiveness for the USS CONSTELLATION depending on the amount of protection (80 to 90%) and whether the resupply delay time was considered. The cost increased by $27.3M to $35.6M over the benchmark. For NAS Brunswick RIM-AIR provided 70-71% gross and 97-99% net peacetime effectiveness depending on the protection. The NAS Brunswick cost increased by $4.2M to $5.5M over the benchmark.

The wartime gross effectiveness of the RIM-AIR requirement for the USS CONSTELLATION with the current range criteria and 80 to 90% fixed protection was below the OPNAVINST 4441.12A objective of 75%. Quarterly removals above a threshold was found to be the best range criteria with a fixed protection safety level. The cost to meet the OPNAVINST 4441.12A objective with this range rule and 85% fixed protection was $45.7M above the benchmark. This cost was reduced by applying variable protection for computing safety level. The optimization was found to be superior to the simple variable protection. Optimizing the depth with the same quarterly removal range criteria lowered the cost of meeting the objective by $15.1M. Optimizing range and depth further reduced the cost by $3.3M. This represents a 27% reduction.

The peacetime gross and net effectiveness of the RIM-AIR requirement for NAS Brunswick were above the OPNAVINST 4441.12A objective of 65% and 85%, respectively, with the current range criteria and 80 to 90% fixed protection. The only way to lower the effectiveness to the goal was to eliminate the safety level or restrict the range, both of which were deemed undesirable. With the current range criteria and 85% fixed protection, a gross peacetime effectiveness of 71% cost $4.7M more than the benchmark. This same level of cost and effectiveness resulted when the quarterly removal range rule was used with 85% fixed protection. Optimizing depth with the quarterly removal range lowered the cost by $1.9M. Optimizing range and depth further reduced the cost by $.5M. This represents a 31% overall cost reduction.

D. CONSUMABLES ANALYSIS. The benchmark quantities filled the order and ship time and resupply delay time levels but, as with the repairables, there was little left over for a safety level. The cost to provide a full 90 percent safety level for the USS CONSTELLATION was $1.5M. The impact of the safety level deficiency was up to four percentage points gross wartime effectiveness depending on whether the resupply delay time was considered and the assumption made regarding the ordering policy. Assumptions that minimized and maximized the effectiveness were made. Adding an operating level cost $2.8M and increased gross wartime effectiveness 13-25 percentage points. Further addition of the endurance delta level completed the total RIM-AIR requirement $2.0M. Gross wartime effectiveness increased up to two percentage points as a result of this final level.

The total RIM-AIR requirement provided 28-32% gross and 85-97% net wartime effectiveness for the USS CONSTELLATION. This gross effectiveness is far below the OPNAVINST 4441.12A goal of 75 percent. This shortfall is due to the large number of demands for noncandidate items. The maximum gross effectiveness achievable with the ARR candidate data was 34%. Thus, no range criteria could stock enough items to meet the goal. The range by depth criteria was found to stock the most items for a given cost with fixed protection. However, range by depth tends to stock all low cost items with predicted demand greater than zero. The current range criteria is preferable because it has the ability to distinguish between low cost items based on an established demand threshold.

A comparison between fixed protection and variable protection failed to show any benefit to the variable protection approaches for consumables. The large number of demands for noncandidates and high variability of the candidate item characteristics negated the benefits of varying protection. Because fixed protection is simpler and performs as well, it is more desirable. Variable protection will become necessary in the future, however, when item essentiality coding is developed.

V. RECOMMENDATIONS

A. RANGE AND SAFETY LEVEL CRITERIA.

1. Repairables - It is recommended that the optimization be used to determine both range and safety level. That is, the optimization should be used in conjunction with the range by depth criteria.

2. Consumables - It is recommended that fixed protection be used to determine safety level until the completeness and accuracy of the consumable data is improved. It is recommended that range be determined using the current criteria (although not necessarily the current threshold parameter).

B. IMPLEMENTATION.

It is recommended that the RIM-AIR model with the range and safety level criteria recommended above be implemented in both the AVCAL development and provisioning processes at ASO. Implementation of RIM-AIR will impact on cost and ASO workload as discussed below.

1. Cost Impact. The cost to implement RIM-AIR for repairables, while satisfying the OPNAVINST 4441.12A effectiveness goals, is $27.3M more than the benchmark for the USS CONSTELLATION and $2.3M more for NAS Brunswick. The ASO order and ship time initiative for 2R/8R cog items accounts for $2.9M of the USS CONSTELLATION increment. The cost of implementation can be reduced for both activities by applying constrained order and ship times. The impact of using the constrained order and ship times used by ASO in their 2R/8R cog initiative; i.e., 12 days for CLAMP and 30 days for non-CLAMP items, is shown in TABLE XII. The costs in TABLE XII are stratified into POS, WRMR and endurance delta dollars. As shown, constraining the order and ship times

reduces the cost increments to $15.5M for the USS CONSTELLATION (in addition to the $2.9M for the 2R/8R initiative) and $1.1M for NAS Brunswick. These cost increments are minimums because the ARR data used in this study understated cost.

TABLE XII
Cost of Optimized RIM-AIR for Repairables

USS CONSTELLATION	Range	Total $ Value	POS $ Value	WRMR $ Value	END Δ $ Value
Unconstrained OST	6,428	49.5M	29.6M	11.9M	8.0M
Constrained OST	6,462	40.6M	20.4M	9.6M	10.6M
NAS Brunswick					
Unconstrained OST	1,819	5.4M	4.2M	N/A	1.2M
Constrained OST	1,797	4.2M	3.0M	N/A	1.2M

Because of the large number of demands for noncandidate items, it was not possible to quantify the cost to meet the OPNAVINST 4441.12A effectiveness goals for consumables. The cost impact for consuambles will depend on the protection level and demand threshold used.

It is realized that funding for the cost increments discussed above will be spread out over a period of time if RIM-AIR is implemented. RIM-AIR can accommodate a phased in approach. Repairables can be optimized to a series of increasing cost targets. Support for consumables can be increased by adding an order and ship time level and incrementally increasing protection.

2. Impact on ASO Workload. The optimization requires user intervention to establish a Lagrange Multiplier. While ASO has experience with the concepts of an optimziation in provisioning, these concepts will be new to the AVCAL development process. Training of ASO personnel in the procedures required to find the proper Lagrange Multiplier will therefore be necessary.

The optimization will be used to compute a gross AVCAL. This gross AVCAL will be subject to a quality review during which the characteristics of some items may be changed. New requirements must be computed for these items. If the number of items requiring a recomputation is small, new requirements can be computed manually with the Lagrange Multiplier used to produce the gross AVCAL. This will distort the optimization somewhat, but not to a significant extent. If a large number of items require recomputation, the distortion introduced by applying the gross AVCAL Lagrange Multiplier will be unacceptable. This means requirements must be reoptimized. A reoptimization of the entire inventory may be undesirable. Requirements for items not affected by the review would change. A constraint can be added to the optimization that the requirements for such items remain unchanged. The optimization would only act on the subset of the inventory affected by the review. A new Lagrange Multiplier would be found that generates new requirements for the affected items which when coupled with the constraint requirements meet the cost/effectiveness target.

The UICP AVCAL system under development at FMSO will use a Weapons System File (WSF) top-down breakdown to extract candidates. This will improve the candidate data. With an expanded candidate file, it should be possible to improve the predicted gross consumable effectiveness. It should also be possible to identify the demand threshold that, when used with the current range criteria, produces gross effectiveness that meets the OPNAVINST 4441.12A goal given a certain level of net effectiveness. Until the improved candidate data is available, however, the establishment of a demand threshold for consumables will be a subjective matter.

APPENDIX A - REFERENCES

1. ALRAND Working Memorandum 352 of 14 Mar 1980
2. COMNAVSUPSYSCOM ltr 04A3/PRV of 17 Mar 1982
3. COMNAVSUPSYSCOM ltr 04A3/PRV of 13 Apr 1981
4. FMSO ltr 9321-E66/JWG/102 5250 of 13 Apr 1982
5. FMSO ltr 9321-E65/E66/FCS/225 5250 of 10 Aug 1982
6. FMSO ltr 9321-E65/FCS/38 5250 of 18 Feb 1981

APPENDIX B - DATA SCREENING

The screening process was to eliminate items that had potentially erroneous data entries which could distort the results of the study. ASO provided criteria for screening candidate data based on the extended dollar value of the quarterly removal forecast. Quarterly removals are forecast by multiplying the sum of the RPF and MRF by the installed population and projected flying hours for each item. A wartime flying hour program was used in the screening for both activities. When the extended dollar value of the quarterly removal forecast for a USS CONSTELLATION repairable candidate exceeded $175,000, the item was deleted. A $250,000 cutoff figure was used for NAS Brunswick repairables. USS CONSTELLATION consumables were deleted when the extended dollar value of quarterly removals exceeded $35,000. These cutoffs are based on the subjective judgement of ASO personnel.

In addition to the ASO screening criteria, a maximum total pipeline quantity was computed for each item. This screening was used to eliminate any items that would require calculations that were beyond the capacity of the hardware used to conduct the study. The maximum total pipeline for the USS CONSTELLATION is the sum of a wartime repair cycle level, wartime OST level and 90 day RDT level. For NAS Brunswick, a peacetime repair cycle level, OST level and an endurance delta computed to support a 90 day endurance period at peacetime flying hours were summed to get the maximum total pipeline. When the maximum total pipeline quantity for any item exceeded 175, the item was deleted. Two 9 cog consumables were also deleted because their wartime flying hour program was less than their peacetime flying hour program. A breakdown by cog of what items were deleted under what criteria is provided in TABLE B-I.

TABLE B-I

Deletion Criteria

	USS CONSTELLATION	NAS BRUNSWICK
Total Candidates deleted	454	31
Excessive removal $	55	27
Excessive pipeline	397	4
War less than Peace	2	0
Repairable Candidates deleted	61	31
Excessive removal $	49	27
Excessive pipeline	12	4
2R deleted	50	26
Excessive removal $	49	26
Excessive pipeline	1	0
1R deleted	0	1
Excessive removal $	0	1
Excessive pipeline	0	0
Consumable Candidates	393	N/A
Excessive removal $	6	
Excessive pipeline	385	
War less than Peace	2	
1R deleted	34	N/A
Excessive removal $	5	
Excessive pipeline	29	
9 cog deleted	348	N/A
Excessive removal $	1	
Excessive pipeline	355	
War less than peace	2	

The repairable deletion accounted for 31% of the total wartime quarterly removals for all extracted USS CONSTELLATION repairable candidates. The majority of repairable deletions were the result of an excessive extended dollar value of the quarterly removal forecast. Forty-one of the USS CONSTELLATION repairables dropped for this reason were stocked on the ASO AVCAL for a total dollar value of $6.1M. All of the USS CONSTELLATION repairables dropped because the maximum total pipeline was excessive were stocked for a total dollar value of $10.4K. Eleven of these items were 9 cog repairables.

While the existance of a 9 cog repairable is not impossible, these items probably result from an incorrect SM&R code. Although having a low dollar value on the ASO AVCAL, these items accounted for 23% of the total wartime quarterly removals forecast for all extracted USS CONSTELLATION repairable candidates.

The repairables deleted for NAS Brunswick accounted for 36% of the peacetime quarterly removals for all NAS Brunswick repairable candidates. Eighteen of the NAS Brunswick repairables that were deleted because of an excess extended forecast were stocked on the ASO AVCAL. The total dollar value of the ASO AVCAL requirements was $983K. None of the NAS Brunswick repairables dropped because of an excessive pipeline were stocked on the ASO AVCAL. These items were all 9 cog repairables and accounted for 11% of the total peacetime quarterly removals for all NAS Brunswick repairable candidates.

The consumable deletions accounted for 68% of the total wartime quarterly removals for all USS CONSTELLATION consumable candidates. The majority of consumable deletions were the result of an excessive pipeline. The excessive pipeline deletions accounted for 67% of the removals forecast for all consumables. The majority of the excessive pipeline deletions were for 9 cog items. The 9 cog excessive pipeline deletions accounted for 63% of the removals for all consumables.

Most of the deleted consumable removals were concentrated in an small number of items. All but one of this small subset were deleted because of an excessive pipeline. There were 36 items with quarterly demand forecasts in excess of 1,000 units deleted because of an excessive pipeline. These 36 items accounted for 38% of the total consumable quarterly removals. A total of 377 of the excessive pipeline deletions were stocked on the ASO AVCAL for a total dollar value of $60K.

Only six consumables were deleted because of an excessive extended dollar value of quarterly removals. Five of these items were stocked on the ASO AVCAL for a total dollar value of $143K. These items accounted for only about 1% of the total removals forecast for all consumables. Most of these removals were for one item with a quarterly removal forecast in excess of 2,000 units. Both items deleted because the wartime flying hour program was less than the peacetime flying hour program were stocked on the ASO AVCAL but with a total dollar value of only $623. The forecasted quarterly removals for these two items were almost zero.

APPENDIX C - SAFETY LEVEL BREAKDOWN

The safety level determination and breakdown described below is graphically illustrated in Figure C-1. The total safety level may be subdivided into a peacetime safety level, wartime safety level and endurance delta safety level as follows:

1. Compute peacetime safety level. The smallest integer is found that provides the required protection (either fixed protection level or protection level computed by variable protection techniques) on the peacetime repair cycle and OST levels. The peacetime safety level is computed by subtracting the peacetime repair cycle and OST levels from this integer.

2. Constrain the peacetime safety level. If the peacetime safety level exceeds the total safety level then no additional safety stock is required to support the wartime flying hour program and endurance delta. In this case, the peacetime safety level is constrained to total safety level and the wartime and endurance delta safety levels are zero. Otherwise, the total safety level includes additional safety stock to support the wartime flying hours and possibly the endurance delta. These additional increments in safety level stock are computed below.

3. Compute the gross wartime safety level. If the peacetime safety level is less than the total safety level, the smallest integer is found that provides the required protection on the wartime repair cycle, OST and RDT levels. The gross wartime safety level is computed by subtracting the same wartime levels from this integer.

4. Compute the net wartime safety level. If the gross wartime safety level exceeds the peacetime safety level, the net wartime safety level is computed as the difference. Otherwise, the net wartime safety level is zero.

5. Constrain the net wartime safety level. If the net wartime safety level is greater than the total safety level minus the peacetime safety level it is constrained to this difference. In this case, the endurance delta safety level is zero.

6. Compute the endurance delta safety level. If the net wartime safety level is less than the total safety level minus the peacetime safety level, the difference is the endurance delta safety level. That is, the endurance delta safety level is the total safety level minus the sum of the peacetime and net wartime safety levels when this difference is positive.

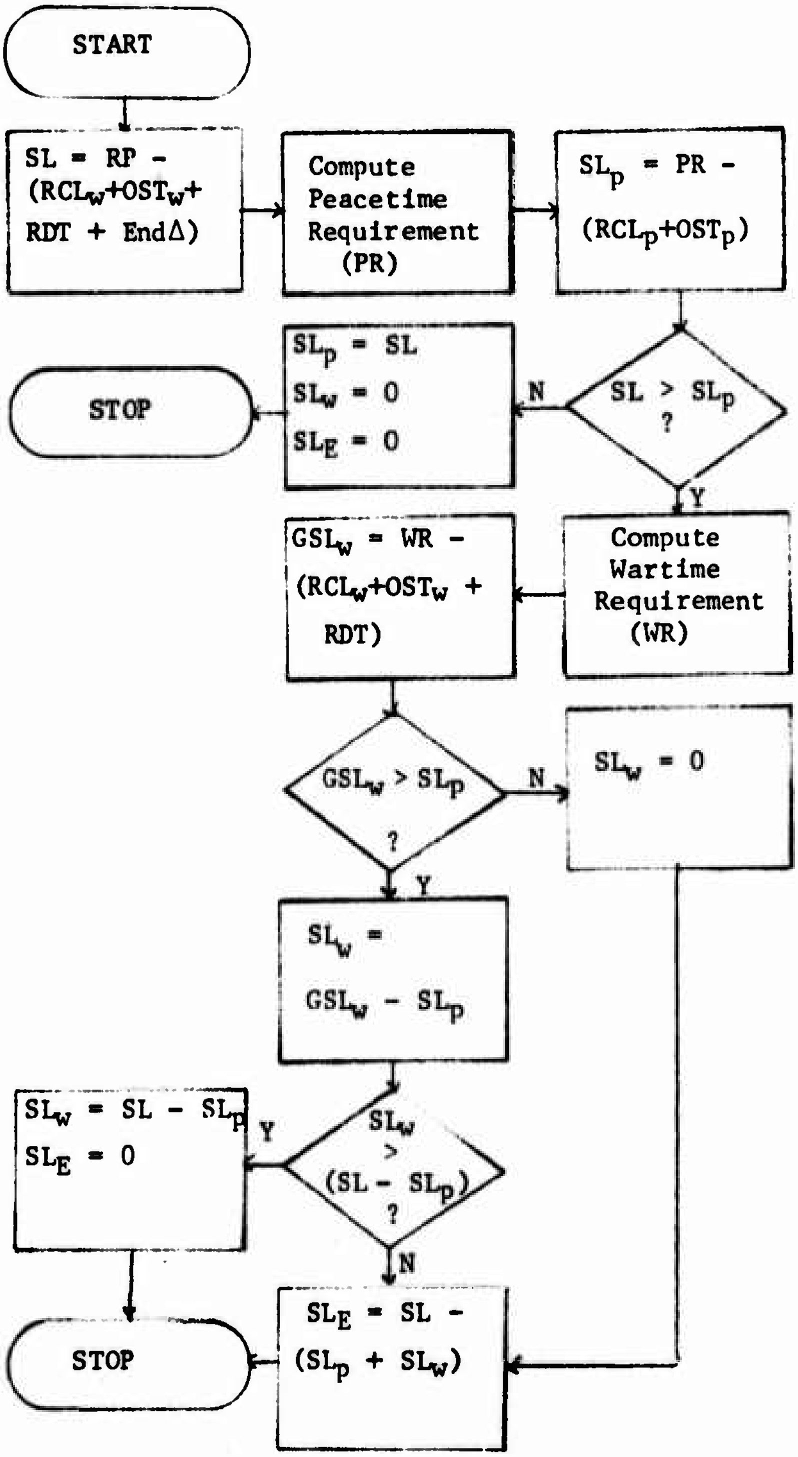

Figure C-1 - Safety Level Breakdown Logic Flow

APPENDIX D - MATHEMATICAL BACKGROUND

1. Steady State Supply Effectiveness. Figure I depicts the movement of an item through the repair and requisitioning processes at an activity.

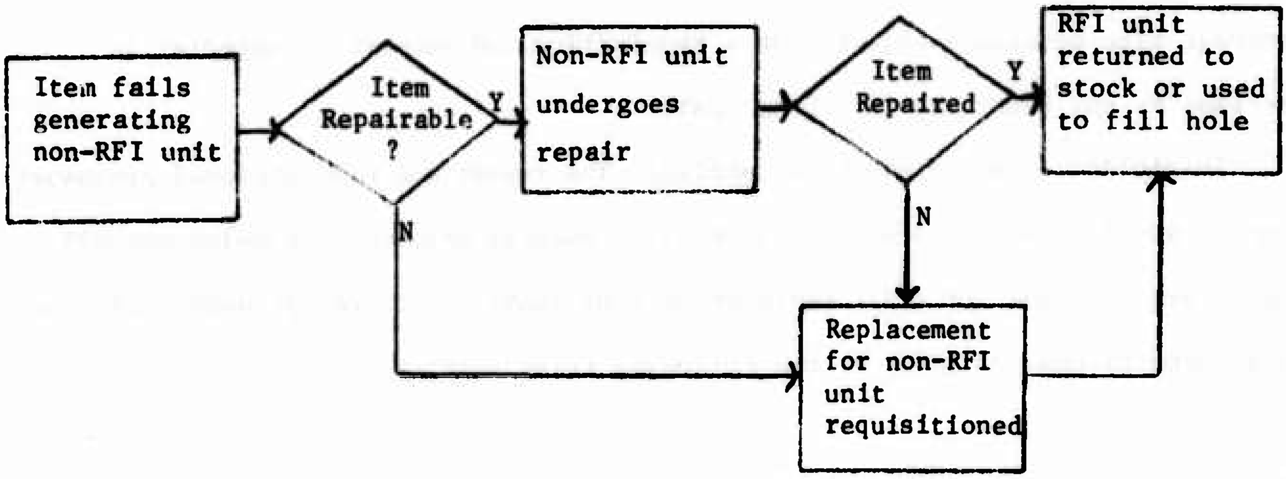

Figure I - Flow Through Activity Repair/Requisitioning Processes

As units fail, repairable items are inducted into the repair process where they are repaired at an average rate defined by the Rotatable Pool Factor (RPF) or found to be Beyond Capability to Maintain (BCM) at a rate defined by the Maintenance Replacement Factor (MRF). The average time an item spends in the repair process is defined by the Turnaround Time (TAT). BCM actions are assumed to be instantaneous so the TAT for BCMed units is zero. BCMed units enter the requisition process as do failed consumable units. The time spent in the requisition process consists of the time spent waiting to submit a requisition and the time it takes to receive an RFI replacement once the requisition is submitted. The time spent waiting to place a requisition for a repairable is assumed to be zero because repairables are requisitioned on a one-for-one basis.

Consumables on the other hand, are requisitioned in quantities greater than one. The time spent waiting to place a requisition for a consumable is therefore a function of the operating level. This waiting time represents a kind of pre-requisition period. It was assumed this waiting time, on the average, equaled one half the operating level minus one expressed as days of demand. The average time between submission of a requisition and receipt of material is defined by the Order and Ship Time (OST).

Initially assume no stock is carried. The repair and requisitioned processes can be modeled mathematically as stochastic queuing processes in which non-RFI units arrive, wait for a RFI replacement then leave. The average number of items in a queuing process is given by the following relationship:

$$L = \lambda * W$$

where

L = average number of units in process

λ = average arrival rate

W = average waiting time in process

The number of non-RFI units in the repair process is called the repair pipeline. The number of requirements for a RFI replacement in the requisition process is the requisition pipeline. Given the above relationship, the average number of non-RFI units in the repair and requisition pipelines may be expressed as follows:

$$
\begin{aligned}
L_T &= L_{REP} + L_{REQ} \\
&= \lambda_{REP} * W_{REP} + \lambda_{REQ} * W_{REQ} \\
&= \frac{RPF * MC_{90}}{90} * TAT + \\
&\quad \frac{MRF * MC_{90}}{90} \left(\frac{(OL - 1) * 90}{2 * MRF * MC_{90}} + OST \right) = \\
&\quad \frac{RPF * MC_{90}}{90} * TAT + \frac{(OL - 1)}{2} + \frac{MRF * MC_{90}}{90} * OST
\end{aligned}
$$

where

L_T = total non-RFI units waiting for replacement

L_{REP} = non-RFI units in the repair process

L_{REQ} = non-RFI units in the requisition process

λ_{REP} = arrival rate for repair process

λ_{REQ} = arrival rate for requisition process

W_{REP} = waiting time for repair process

W_{REQ} = waiting time for requisition process

MC_{90} = maintenance cycle program for 90 days

OL = operating level

The (OL - 1)/2 term in L_T is a kind of prerequisition pipeline for consumables. This prerequisition pipeline varies between zero and OL - 1 assuming an order is placed as soon as the reorder point is reached. The repair and requisition (excluding the prerequisition) pipelines are not bounded in this manner. The actual number of units in the repair and requisition pipelines at some point in time is a random variable. The following assumptions are made in order to postulate a probability density function for this random variable:

- The arrival process is Poisson.
- The waiting times have an arbitrary distribution independent of the arrival process (this means that the service provided by the process begins as soon as an arrival occurs and the time to provide the service is independent of the arrival process).
- The average arrival rates and average waiting times are constant over time.
- Arrivals are always single units.
- Every arrival enters either the repair or requisition process and completes service before departing.

Given these assumptions, the Palm Theorem[1] states that the number of units (n) in the repair and requisition pipelines will be Poisson distributed with mean L_T for repairables. That is:

$$P(n) = \frac{e^{-L_T} * L_T^n}{n!}$$

Here the prerequisition pipeline vanishes because the operating level is one. When the prerequisition pipeline is included in the mean of the Poisson distribution for consumables, it is assumed implicitly that the prerequisition is unbounded which is not true. This means the probability that the total pipeline (prerequisition and requisition) is less than the operating level is understated. The probability that the total pipeline is very large is overstated because it considers large prerequisition pipelines feasible. Thus, the probability that exactly n consumable units are in the total pipeline can only be approximated by the above Poisson probability.

If a stock quantity is positioned at an activity for the purpose of immediately providing a RFI replacement for a non-RFI arrival, the non-RFI units in the repair and requisition pipelines consist of units being repaired/requisitioned to replace RFI units formerly issued from stock and to satisfy outstanding requirements for material. When the number of non-RFI units in the repair and requisition pipelines is less than or equal to the stock quantity, all the non-RFI units are to replace RFI units formerly issued from stock. There are no backorders being repaired or requisitioned to fill a hole. The probability that there are no backorders is called protection and is computed as follows:

$$\text{Protection} = \sum_{n=0}^{S} P(n)$$

where

S = stock quantity

---

[1] Feller, W., "An Introduction to Probability Theory and Its Applications", Vol. I, Wiley, New York, 3rd Edition, 1968, pp 460-461

When the number of units in the repair or requisition processes is strictly less than the stock quantity, there is at least one RFI unit available in stock to satisfy a demand should one occur. Since demands are assumed to always be for one unit, only one unit needs to be in stock when a demand occurs in order to satisfy that demand. The probability of satisfying a demand is called a Fill Rate (FR) and is computed as follows:

$$FR = \sum_{n=o}^{S-1} P(n)$$

Both protection and the Fill Rate computed in this manner will be understated for consumables because of the way P(n) is approximated. The minimum Fill Rate obtained in this way was used to develop the minimum effectiveness statistics for consumables. Maximum effectiveness was derived by eliminating the prerequisition pipeline from L_T and recomputing P(n) and the Fill Rate. A Fill Rate computed in this manner produces effectiveness statistics representing consumables as though they were requisitioned on a one-for-one basis like the repairables.

The expected number of satisfied demands is found by multiplying the Fill Rate by the expected number of demands. The expected demands (D) for a 90 day period is computed as follows:

$$D = (MRF + RPF) * MC_{90}$$

Thus, the expected gross supply effectiveness, which is the percentage of demands satisfied immediately from stock, can be computed as follows:

Expected Supply Effectiveness =

$$\frac{\sum_{i=1}^{m} FR_i * D_i}{\sum_{j=1}^{N} D_j}$$

where

m = number of stocked items

N = number of installed items

i = index of stocked items

j = index of installed items

Expected net supply effectiveness is obtained by summing expected demand over stocked items in the denominator.

2. Optimization. The objective of the optimization is to find an inventory that gives the maximum possible effectiveness for a given cost. Conversely, the cost to produce a given level of effectiveness is minimized. The effectiveness measure used is the expected gross supply effectiveness derived in the preceding section of this Appendix. Expected gross supply effectiveness is computed by dividing the sum of expected units satisfied across all stocked items by the sum of expected units demanded over all installed items. Expected units demanded for installed items remain constant. The optimization maximizes expected units satisfied which maximizes expected supply effectiveness. The problem may be stated as follows:

$$\text{Maximize} \quad \sum_{i=1}^{m} E_i * D_i * FR_i$$

$$\text{subject to} \quad \sum_{i=1}^{m} C_i * S_i = \alpha$$

where

i = Item index

E_i = Item essentiality code placeholder

D_i = Expected demand (as computed in the previous section of this Appendix)

FR_i = Fill Rate

C_i = Unit price

S_i = Stock quantity

α = Cost target

A technique for solving this problem is to use the method of Lagrange multipliers. The technique involves constructing an unconstrained problem from the original problem which involves a constraint. This is done by formulating the Lagrangean function which in this case is:

$$L(\lambda,\overline{S}) = \sum_{i=1}^{m} E_i * D_i * FR_i - \lambda * \left(\left(\sum_{i=1}^{m} C_i * S_i\right) - \alpha\right)$$

The first term in the Lagrangean function is the objective function being maximized. The second term consists of the constraint function, cost target and a new variable known as a Lagrange multiplier (λ) and is referred to here as the constraint line. The Lagrangean function and the two terms are represented graphically in Figure D-I for the i^{th} item. The stock quantity (S_i) is portrayed as a nondiscrete variable in Figure D-I. It is expeditious to treat the stock quantity as a nondiscrete number when applying the Lagrange multiplier technique. Stock quantities, of course, are always integers. An iterative algorithm for producing integer stock quantities can be derived from the technique.

The Lagrangean function may be optimized by taking the partial derivatives with respect to each S_i and λ and setting them equal to zero. Before this is done, it is necessary to redefine the Fill Rate in continuous terms as follows:

$$\text{Fill Rate} = \int_{o}^{S-1} f(x)\,dx$$

where

$f(x)$ = continuous probability density function for the random variable x representing the number of units in the total pipeline

The Lagrangean function thus becomes:

$$L(\lambda,\overline{S}) = \sum_{i=1}^{n} \left(E_i * D_i * \int_{o}^{S_i-1} f(x)\,dx\right) - \lambda * \left(\left(\sum_{i=1}^{n} C_i * S_i\right) - \alpha\right)$$

Now,

$$\frac{\partial L}{\partial S_i} = E_i * D_i * \frac{d \int_0^{S_i-1} f(x)\, dx}{dS_i} - \lambda C_i$$

$$= E_i * D_i * f(S_i-1) - \lambda C_i$$

and

$$\frac{\partial L}{\partial \lambda} = \left(\sum_{i=1}^{m} C_i * S_i \right) - \alpha$$

Setting the partial derivative with respect to λ equal to zero produces the constraint. Therefore, any $\lambda*$ that optimizes the Lagrangean function guarantees that the constraint in the original problem will be satisfied. When this constraint is satisfied, the Lagrangean function reduces to the objective function of the original problem. Therefore, any set of stock quantities $\bar{S}^*$ that optimizes the Lagrangean function also optimizes the original objective function. Thus, the original constrained problem reduces to finding λ^* and $\bar{S}^*$ that optimize the unconstrained Lagrangean function. Setting the partial derivative with respect to S_i to zero it is found that the optimal stockage quantity for the i^{th} item is that which satisfies the following:

$$f(S_i - 1) = \frac{\lambda * C_i}{E_i * D_i}$$

If the probability density function f(x) decreases as x increases there will be a unique S_i that satisfies the above condition, if it is satisfied at all. However, if f(x) increases, reaches a peak then decreases, there will be two S_i's that satisfy this condition, if it is satisfied. One S_i will be to the left of the mean of the density function and one to the right. The impact of this situation on the Lagrangean function is illustrated in Figure D-I.

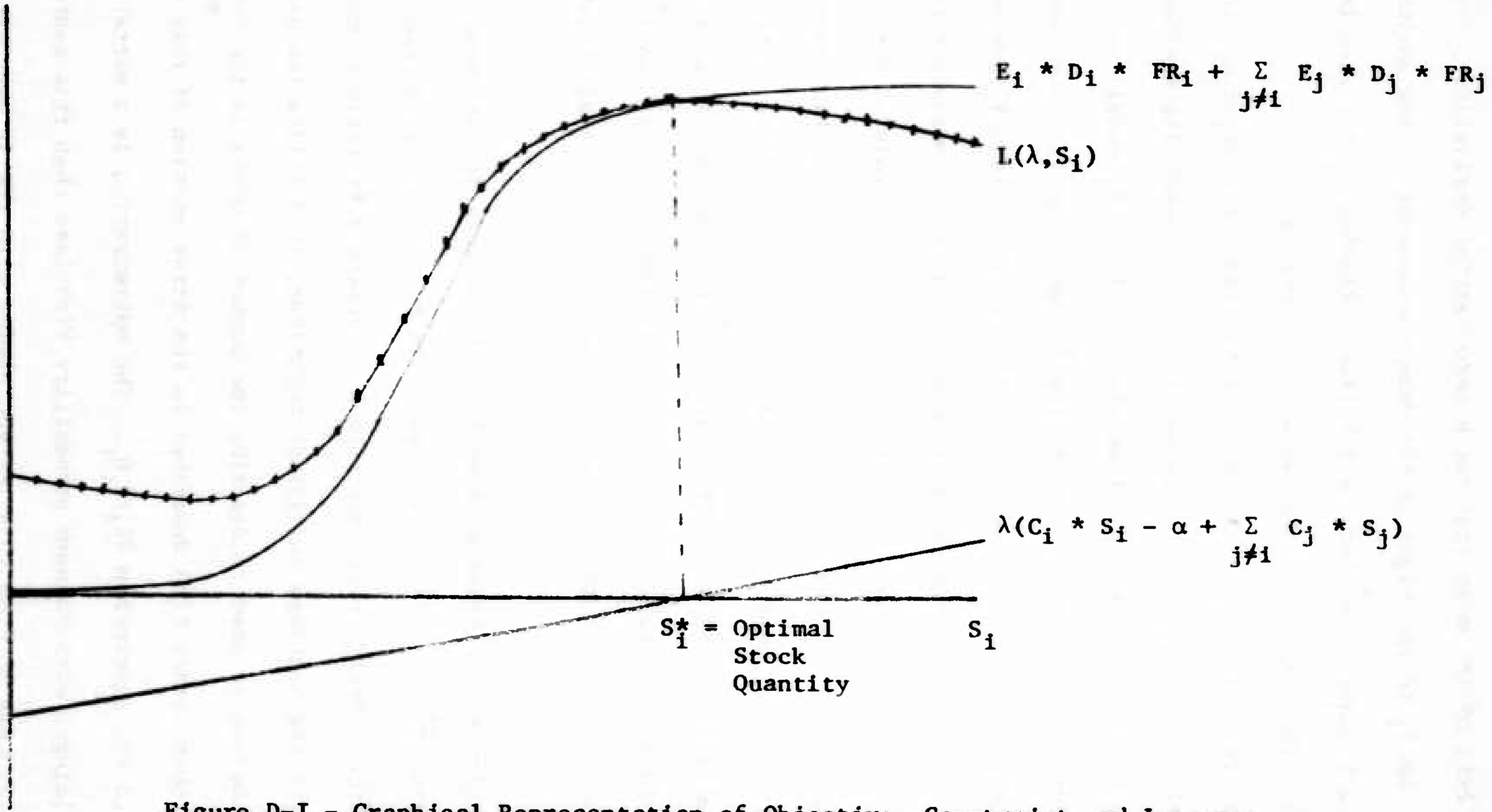

Figure D-I - Graphical Representation of Objective, Constraint and Lagrange Functions for the ith Item

NOTE: i is any arbitrary item with all other items j already at their optimum S_j^* and λ^* is the optimum Lagrange multiplier.

As shown, the Lagrangean function initially decreases slightly before increasing to a maximum. The Lagrangean function therefore has a minimum and a maximum. The S_i to the left of the mean that has a zero partial derivative corresponds to the minimum. The S_i to the right of the mean corresponds to the maximum. This is the optimal stock quantity S_i^* for the i^{th} item. Finding S_i^* for each item i yields an inventory $\bar{S}^*$ that maximizes the Lagrangean function.

It is possible that $f(S_i-1)$ will be strictly less than $\lambda C_i/E_iD_i$ everywhere for some items. This means the Lagrangean function reaches its maximum at S_i equal to zero, so the item should not be stocked; i.e., S_i^* equals zero.

The procedure outlined above for finding $\bar{S}^*$ can be applied with any value of λ. When used with λ^*, it produces the solution to the original problem. When used with any other λ, it produces an inventory that still maximizes the Lagrangean function with respect to $\bar{S}$ but does not satisfy the constraint. Hence, the Lagrangean function is not optimized with respect to λ. The technique of Lagrange multipliers, therefore, comes down to finding λ^*. This is done by trial and error. A λ is selected and $\bar{S}^*$ computed. The cost of $\bar{S}^*$ is compared to α. If it is sufficiently close, λ is taken to be a good approximation of λ^* and $\bar{S}^*$ is accepted as solution. If not, λ is adjusted and the process is repeated until λ^* is found.

Stock quantities were treated as nondiscrete numbers in the above discussion to permit finding $\bar{S}^*$ using differentiation. In practice, only integer values of S_i are considered. While it is expeditious to create a fictitious continuous $f(x)$ to describe the Lagrange multiplier technique, in practice the discrete Poisson distribution is used to describe the number of units in the total pipeline. The Poisson probabilities $P(n)$ described in the first section of this Appendix are compared to the expression $\lambda C_i/E_iD_i$. The optimization is a matter of finding the smallest integer with Poisson probability $P(n)$ less than this expression. The iterative process to find this integer begins with the integer with maximum

Poisson probability. If L_T (the mean of the Poisson distribution defined in the first section of this Appendix) is not an integer, the integer with maximum Poisson probability is the largest integer which is less than the mean. If L_T is an integer, both it and L_T minus one have equal probability greater than any other integer. The search for the optimal stock quantity S_i^* therefore begins with the largest integer which is less than or equal to L_T and proceeds by comparing the probability of successively larger integers to $\lambda C_i/E_iD_i$ until an integer is found with probability less than this expression. This guarantees the process will find the maximum, not the minimum of the Lagrangean function. If the maximum Poisson probability is less than the expression, the optimal inventory quantity is zero; i.e., the item should not be stocked. The algorithm applied to find S_i^* for each item given λ is summarized below:

a. Find the largest integer which is less than or equal to L_T as an initial value for S_i.

b. If

$$P(S_i) < \frac{\lambda * C_i}{E_i * D_i}$$

do not stock the item; otherwise go on to c.

c. Increment S_i by one.

d. If

$$P(S_i) < \frac{\lambda * C_i}{E_i * D_i}$$

select S_i as S_i^* and stop; otherwise, go to step c.

This algorithm generates the solution to the original problem of maximizing units satisfied, and hence, supply effectiveness, for a given cost. The converse problem of minimizing the cost to achieve a given level of supply effectiveness can also be solved with this algorithm. A direct solution of the converse problem involves a λ which is the negative reciprocal of the λ used here. However, both problems are solved by finding the $\lambda*$ that produces the cost or effectiveness desired.

3. <u>Constraining the Optimization</u>. If the optimization algorithm described in section 2 of this Appendix is applied to each candidate for stockage, it will

select the optimum mix of range and depth to achieve a cost/effectiveness target. Optimum, that is, if the item characteristics upon which the decisions are based are accurate. In reality, these item characteristics are forecasts which are subject to an unknown degree of variability. The effect of this variability on expected supply effectiveness is discussed in the Approach. The variability of item characteristics also has an impact on the optimization. Inaccurate forecasts can cause the optimization to select deficient or excessive stock quantities for certain items. While the impact of imperfect forecasting cannot be eliminated, it can be minimized by placing constraints on the stock quantities selected by the optimization. The constraining of an optimization is beneficial if done in moderation. Unfortunately, there is a tendency to add more and more constraints over time. Excessive constraining can eventually destroy the optimization process itself. Stock quantities entirely set by constraints result.

The constraints used for the purposes of this study were minimal. A minimum stock quantity consisting of an operating level, repair cycle level, order and ship time level, resupply delay time level and endurance delta level is computed for each item. These unprotected levels are summed and the total is .5 rounded to produce the minimum. A maximum stock quantity consisting of a repair cycle level, order and ship time level, resupply delay time level and endurance delta level protected to 99% is also computed. An additional operating level minus one unit are added for consumables to support the units waiting to be requisitioned. The optimal stock quantity selected by the optimization is compared to the minimum and maximum stock quantities and constrained accordingly. The constrained stock quantities are used to compute the cost and effectiveness associated with a given λ.

APPENDIX E - ANALYSIS OF ALTERNATIVE RANGE CRITERIA

1. <u>Repairables</u>. The alternative range criteria described in the Approach were used in conjunction with RIM-AIR protected to 85% and the results analyzed. The analysis was accomplished as follows. First, the range, cost and effectiveness of RIM-AIR with range determined by depth were computed. Next, a RIM-AIR inventory with a range determined by the current range criteria was developed. The current range criteria splits attrition and repair demand. The repair demand was eliminated if it was determined that no stock was required to provide 85% protection on the repair pipeline. This is true when the repair cycle level is less than .1625. As long as the repair cycle level was .1625 or more it was included in the depth computation and supported by the total RIM-AIR stock quantity. Similarly, attrition demand was eliminated if below the attrition threshold. When above the attrition threshold, the attrition demand forecast was used to compute OST, RDT and endurance delta levels in the depth computation. An item was stocked if the repair cycle level was .1625 or more or the attrition threshold was surpassed, i.e., both the attrition and repair demand were not eliminated.

The attrition thresholds currently used by ASO produced activity inventories costing less than those produced by the range by depth criteria. It was necessary to lower the attrition thresholds until the costs associated with the current range criteria equaled the range by depth costs. In this way, the range of items stocked and resulting gross effectiveness produced by each criteria for a given cost was determined and a comparison made. The attrition threshold values obtained in this manner for each activity are shown in TABLE E-I along with range, cost and effectiveness statistics for the current and range by depth criteria. Similarly, removal thresholds were found that produced costs for activity inventories constructed with the quarterly removals above a threshold criteria equal to the range by depth costs. These removal threshold values are also shown in TABLE E-I along with statistics for the quarterly removal above a threshold criteria.

TABLE E-I

Alternative Range Criteria with 85% Fixed Protection Repairables

USS CONSTELLATION	Range	Total $ Value	Peacetime Effectiveness		Wartime Effectiveness w/o RDT		Wartime Effectiveness with RDT	
			Gross	Net	Gross	Net	Gross	Net
Current Criteria Item stocked if repair cycle level $\geq$ .1625 or item attrited once every 2.4 yrs.	5,254	64.1M	75	99	73	97	70	93
Range determined by depth	5,330	64.1M	75	99	74	97	71	93
Items stocked if removed once every 1.4 yrs.	5,761	64.1M	79	98	77	96	74	92
Items stocked by Accommodation Index	2,433	41.7M	70	98			67	93
<u>NAS Brunswick</u>								
Current Criteria Item stocked if repair cycle level $\geq$ .1625 or item attrited once every 1.6 yrs.	1,959	10.1M	72	98				
Range determined by depth	2,003	10.1M	72	98				
Items stocked if removed once every 11 mos.	2,058	10.1M	73	98				
Items stocked by Accommodation Index	356	3.0M	57	99				

TABLE E-I shows that the quarterly removals above a threshold criteria stocks the most items and produces the highest gross effectiveness for a given cost. It is the best range rule for RIM-AIR with fixed protection. If quarterly removals above a threshold is best, the threshold for an activity must be determined. As discussed in the Approach, NAVSUPSYSCOM proposed using an activities Accommodation Index to establish a threshold. This was done for the study activities and the results are shown in TABLE E-I. The Accommodation Index for the USS CONSTELLATION produced a range with over 1,200 fewer items than the benchmark range which was 3,680. The Accommodation Index for NAS Brunswick produced a range with just under 1,200 fewer items than the benchmark range which was 1,535. The gross effectiveness produced by the Accommodation Index was below the .12A goals for both activities. The reason the Accommodation Index produced a lower range and fell short of the .12A gross effectiveness goals was that it did not consider demand for noncandidate items. If adjusted to consider noncandidate demand, the Accommodation Index can be used to identify the quarterly removal threshold that produces a gross effectiveness goal given a certain level of net effectiveness.

The alternative range criteria were also analyzed when used in conjunction with the optimization. The results are shown in TABLE E-II. In order to make a comparison based on the effects of the range criteria alone, it is necessary to keep the depth computation constant. With the optimization, the stockage quantity for a particular item is based on the relative cost/effectiveness of all the items in the inventory. This means the stockage quantity for a particular item is affected by the range of items stocked and hence the range criteria. To make a valid comparison of different range criteria with the optimization, the same Lagrange Multiplier must be used. This assures that the stockage quantities computed for an item stocked by the different range criteria will all be the same.

TABLE E-II

Alternative Range Criteria with Optimization Repairables

USS CONSTELLATION	Range	Total $ Value	Peacetime Effectiveness		Wartime Effectiveness w/o RDT		Wartime Effectiveness with RDT	
			Gross	Net	Gross	Net	Gross	Net
Current Criteria Item stocked if repair cycle level $\geq$ .11 or item attrited once every 2.9 yrs.	5,546	53.0M	76	99	75	97	73	94
Range determined by depth	6,671	52.9M	79	98	78	97	76	94
Items stocked if removed once every 1.25 yrs.	5,665	53.0M	79	98	78	97	76	94
<u>NAS Brunswick</u> Current Criteria Item stocked if repair cycle level $\geq$ .11 or item attrited once every 1.5 yrs.	1,961	7.8M	73	99				
Range determined by depth	2,586	7.8M	74	99				
Items stocked if removed once every 9 mos.	1,881	7.8M	73	99				

The Lagrange Multipliers used to produce the statistics presented in TABLE E-II were determined by optimizing the range by depth criteria to a cost target. The cost target used was the cost of RIM-AIR with 85% fixed protection with the benchmark range criteria shown in TABLEs VII and VIII in the main body of the report. The Lagrange Multipliers found for each activity in this manner were used with the current and quarterly removals above a threshold criteria. The cost target was achieved with these two criteria by altering the attrition and removal thresholds. The Accommodation Index was not examined with the optimization because it is a mechanism for establishing a quarterly removal threshold and not a separate range criteria.

The results in TABLE E-II show that range by depth and quarterly removals above a threshold both produced the same effectiveness for approximately the same cost for the USS CONSTELLATION. The range of items stocked, however, were decidedly different. The range determined by depth exceeded the range produced by quarterly removals above a threshold by over 1,000 items. Both range by depth and quarterly removals above a threshold produced about three percentage points more gross effectiveness than the current criteria for the same cost. The results for NAS Brunswick show that range determined by depth produces one percentage point more gross effectiveness than the current and quarterly removals above a threshold criteria for the same cost. Range by depth also produced the largest range by stocking over 600 items more than the other criteria.

Both range by depth and quarterly removals above a threshold produce about the same effectiveness for the same cost. To choose the best range criteria, consideration must be given to what is required to apply the criteria. Quarterly removals above a threshold requires a threshold. An adjusted

Accommodation Index can be used to find a threshold that produces a gross effectiveness goal given a certain level of net effectiveness. Net effectiveness is dependent upon the Lagrange Multiplier. To select a Lagrange Multiplier, thresholds associated with several Lagrange Multipliers would have to be generated. Each Lagrange Multiplier would result in a different level of depth and hence net effectiveness. In this way, a variety of range and depth combinations that meet the gross effectiveness goal could be compared. The combination that meets the goal at least cost would be best.

The procedure outlined above for determining a threshold would be cumbersome to apply in practice. The alternative would be to arbitrarily assign a threshold and optimize to the gross effectiveness goal. This approach is not likely to produce the most cost/effective mix of range and depth and hence will cost more. Finding the right mix of range and depth is primary advantage of using the range by depth criteria with the optimization. When range is determined by depth and the depth is optimized the optimal combination of range and depth is found. Applying the range by depth criteria is simply a matter of optimizing to a cost/effectiveness goal. Optimizing range does have a possible undesirable side effect. Intuitively, an optimized range would seem more likely to vary across successive requirement recomputations than quarterly removals above a threshold. Such churn in the items stocked from AVCAL to AVCAL is costly. An item could be dropped from the range and offloaded as excess only to be added back to the range as a deficiency. The amount of churn that would be generated by an optimized range is unknown. However, should it prove to be substantial it could be overcome by the addition of a constraint on the optimized range that considers past stockage and demand. The constraint would force an item to be stocked if a requirement already exists and it was demanded in the past even if the forecasted future demand was insufficient to justify stockage.

2. Consumables. The current and range by depth criteria were used in conjunction with RIM-AIR protected to 85%. Quarterly removals above a threshold was not analyzed separately because this criteria is the same as the current for consumables. Both criteria stock items based on predicted attrition demand above a threshold. The range, cost and effectiveness of RIM-AIR with range determined depth were computed first. Next, a RIM-AIR inventory with a range determined by the current range criteria was developed. The attrition thresholds currently used by ASO produced an inventory costing less than that produced by the range by depth criteria. It was necessary to lower the attrition thresholds until the cost associated with the current range criteria equaled the range by depth cost. In this way, the range of items stocked and resulting gross effectiveness produced by each criteria for a given cost was determined and a comparison made. The attrition threshold obtained in this manner is shown in TABLE E-III along with range, cost and effectiveness statistics for the current and range by depth criteria.

TABLE E-III shows that the range by depth criteria stocks over 3,000 more items than the current criteria for the same cost. Both criteria produce the same level of effectiveness. From this it would appear that the additional items stocked by the range by depth criteria contributed nothing to effectiveness. The effectiveness of the current range criteria is already close to the maximum achievable with the ARR candidates. The addition of a few thousand low demand items does little to increase effectiveness. As with the repairables, using the Accommodation Index to establish an attrition threshold produced a depleted range. Although this reduced range was less than a third of that produced by the current and range by depth criteria, the effectiveness only decreased a few percentage points. Apparently, a large portion of the consumable demands for candidate items are for a small number of items.

TABLE E-III

Alternative Range Criteria with 85% Fixed Protection Consumables

USS CONSTELLATION	Range	Total $ Value	Peacetime Effectiveness		Wartime Effectiveness w/o RDT		Wartime Effectiveness with RDT	
			Gross	Net	Gross	Net	Gross	Net
Current Criteria Item stocked if attrited once every 2.5 years	26,151	10.9M	32-33	94-99	31-33	91-96	29-31	85-91
Range determined by depth	29,345	10.9M	32-33	94-99	31-33	91-96	29-31	85-91
Items stocked by Accommodation Index	7,192	4.7M	28-28	98-100	27-28	96-99	26-27	90-95

The operating level drives the range selection for low cost items with the range by depth criteria. This is because a positive Wilson EOQ is computed for a low cost item even if the predicted demand is extremely low. A positive operating level guarantees stockage. This explains why range by depth stocked more items than the current criteria. Almost all low cost items with predicted peacetime demand greater than zero were stocked. This tendency to stock every low cost candidate is not very practical. The current criteria has the ability to differentiate between low cost items. The only requirement is that a demand threshold must be established. As discussed in the repariables section of this Appendix, an adjusted Accommodation Index can be used to identify a threshold that produces a gross effectiveness goal given a certain level of net effectiveness. Unfortunately, because of the large number of demands for noncandidate items, the OPNAVINST 4441.12A gross effectiveness goal can never be achieved with the ARR candidate data used is this study. The adjusted Accommodation approach will stock every ARR consumable candidate, just as the range by depth criteria did, in attempting to reach the goal. Thus, until the consumable candidate data is improved, the establishment of a demand threshold will be a purely subjective matter.

APPENDIX F - FIXED VS. VARIABLE PROTECTION APPROACHES TO SAFETY LEVEL

1. Repairables. The variable protection techniques were compared to fixed protection using the current and alternative range criteria described in the Approach. Inventories were constructed with each range criteria by varying the simple variable protection control parameter and the optimization Lagrange Multiplier until the fixed protection cost was approximately reproduced. The current range criteria were applied using the attrition thresholds and the .11 repair cycle cutoff currently used by ASO to produce AVCALs. The attrition thresholds for items not receiving local repair asset support is one unit attrited every nine months for items with a unit price under $5,000. One unit attrited every six months for items with a unit price of $5,000 or more. These same thresholds were used with the quarterly removals above a threshold range criteria. That is, an item with a unit price under $5,000 was stocked if it was predicted to be removed once every nine months. If the unit price was $5,000 or more, the item was stocked if it was predicted to be removed once every six months. Range, dollar value and effectiveness statistics for the USS CONSTELLATION are presented in TABLE F-I. Statistics for NAS Brunswick are presented in TABLE F-II.

TABLE F-I

Variable vs. Fixed Protection
USS CONSTELLATION
Repairables

Current Range Criteria	Range	Total $ Value	Peacetime Effectiveness		Wartime Effectiveness w/o RDT		Wartime Effectiveness with RDT	
			Gross	Net	Gross	Net	Gross	Net
85% Fixed	3,680	53.0M	72	98	71	95	68	91
Simple Variable Protection	3,680	52.9M	72*	98**	72	97	71	95
Optimization	3,680	52.8M	73*	99*	72	97	71	95
Range Determined by Depth								
85% Fixed	5,330	64.1M	75	99	74	97	71	93
Simple Variable Protection	5,665	64.0M	78	99	78	98	77	97
Optimization	6,972	64.0M	80	99	79	98	78	96
Quarterly Demands Above a Threshold								
85% Fixed	4,702	57.1M	77	98	76	96	73	93
Simple Variable Protection	4,702	57.1M	78	99	77	98	76	96
Optimization	4,702	57.1M	78	99	77	98	76	96

*Optimization is really only .1 percentage points greater than simple variable protection. Simple variable protection is .6 percentage points greater than 85% fixed protection.

**Optimization is really only .2 percentage points greater than simple variable protection. Simple variable protection is .8 percentage points greater than 85% fixed protection.

TABLE F-II

Variable vs. Fixed Protection
NAS Brunswick
Repairables

Current Range Criteria	Range	Total $ Value	Peacetime Effectiveness	
			Gross	Net
85% Fixed	1,535	7.8M	71	98
Simple Variable Protection	1,535	7.8M	71*	99
Optimization	1,535	7.8M	71*	99
Range Determined by Depth				
85% Fixed	2,003	10.1M	72	98
Simple Variable Protection	2,188	10.1M	74	99
Optimization	2,752	10.1M	75	99
Quarterly Removals Above a Threshold				
85% Fixed	1,861	9.4M	73	98
Simple Variable Protection	1,861	9.4M	74*	99
Optimization	1,861	9.4M	74*	99

*Simple Variable protection and optimization are .7 and .8 percentage points higher than fixed protection, respectively.

The results presented in both tables show that the variable protection techniques consistently provide higher effectiveness for a given cost than fixed protection. Furthermore, the simple variable protection produced effectiveness almost exactly equal to the optimization for a given cost with the current and quarterly removals above a threshold range criteria. When range was determined by depth, the optimization outperformed the simple variable protection approach for both activities.

The fact that the simple variable protection and optimization produce approximately equal effectiveness for the same cost when the range is determined independently from the depth shows that the simple variable protection approach produces a good approximation to the optimal depth. It does not, however, produce a good approximation to the range selected by the optimization under the range by depth criteria. The optimization selects a greater range of items and produces higher gross effectiveness than the simple variable effectiveness approach.

2. Consumables. The variable protection techniques were compared to fixed protection using the current and range by depth criteria. Inventories were constructed with each range criteria by varying the simple variable protection control parameter and optimization Lagrange Multiplier until the fixed protection cost was approximately reproduced. The current range criteria were applied using the attrition thresholds currently used by ASO to produce AVCALs. The attrition threshold for items with a unit price under $5,000 is one unit attrited every nine months. For items costing $5,000 or more, the threshold is one unit attrited every six months. Range, dollar value and effectiveness statistics are displayed in TABLE F-III.

TABLE F-III

Variable vs. Fixed Protection
USS CONSTELLATION Consumables

Current Range Criteria	Range	Total $ Value	Peacetime Effectiveness		Wartime Effectiveness w/o RDT		Wartime Effectiveness with RDT	
			Gross	Net	Gross	Net	Gross	Net
85% Fixed	19,538	9.1M	31-33	94-99	30-32	92-97	29-30	86-92
Simple Variable Protection	19,538	9.3M	31-33	93-99	30-32	90-96	28-30	83-90
Optimization	19,538	9.1M	31-33	95-99	30-32	92-97	28-30	85-92
Range Determined by Depth								
85% Fixed	29,345	10.9M	32-33	94-99	31-33	91-96	29-31	85-91
Simple Variable Protection	29,456	11.4M	31-33	92-99	30-33	89-96	28-30	83-90
Optimization	30,120	11.1M	32-34	94-99	31-33	91-97	29-31	85-92

The results displayed in TABLE F-III show that all in all the variable protection approaches did no better than fixed protection. Minimum wartime effectiveness, which is explained in detail in Appendix D, was actually lower in many cases. Basically, the effectiveness produced by fixed protection was already close to the maximum possible with the ARR candidates. There was little room for improvement. The fact that the optimization produced lower effectiveness in some cases may seem suprising. However, the optimization assumes perfect forecasting of item characteristics. The result is therefore not optimal once variability in forecasting is introduced. When the variance to mean ratio used to describe the forecasting accuracy is low, as was the case with repairables, the devitaion from the true optimal will be small. With a large variance to mean ratio like the one used for consumables, the deviation becomes noticeable when fixed protection outperforms the optimization.

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Navy Fleet Material Support Operations Analysis Dept. (93) 5450 Carlisle Pike, P. O. Box 2010 Mechanicsburg, PA 17055	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

RIM-AIR

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Frank C. Strauch and Jeffrey W. Gardner

6. REPORT DATE	7a. TOTAL NO. OF PAGES 104	7b. NO. OF REFS 6

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) 155
b. PROJECT NO. 9321-E66	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

Naval Supply Systems Command (COMNAVSUPSYSCOM) proposed the Repairable Integrated Model for Aviation (RIM-AIR) model to compute Aviation Consolidated Allowance List (AVCAL) requirements during the provisioning and AVCAL development processes at Navy Aviation Supply Office (ASO). The AVCAL is a consolidated listing of the range and depth of aeronautical material required by ships, Marine Air Groups (MAGs), and Naval Air Stations to support aircraft operations. RIM-AIR was designed to eliminate the dichotomy between the material availability goals and stockage criteria promulgated in OPNAVINST 4441.12A while complying with the policy established by DODIs 4140.45, 4140.46, and 4140.47. This report analyzes alternative range and safety level criteria for RIM-AIR, recommends specific alternatives and discusses issues relevant to the implementation of these recommendations.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

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