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THESIS

AN ANALYSIS OF THE MARINE CORPS LEVEL-OF-REPAIR MODEL (MCLOR) AND THE NAVY AVAILABILITY-CENTERED INVENTORY MODEL (ACIM) FROM AN OPERATIONAL AVAILABILITY STANDPOINT

by

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December 1983

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An Analysis of the Marine Corps Level-of-Repair Model (MCLOR) and the Navy Availability-Centered Inventory Model (ACIM) from an Operational Availability Standpoint

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LIST OF ABBREVIATIONS

ACIM	Availability-Centered Inventory Model
Ao	Operational Availability
BCM	Beyond Capability of Maintenance
BRF	Best Replacement Factor
CMC	Commandant of the Marine Corps
CONUS	Continential United States
COSAL	Coordinated Shipboard Allowance List
DDP	Data Development Period
DL	Day Level
DLA	Defense Logistics Agency
DOD	Department of Defense
DODI	Department of Defense Instruction
DWT	Division Wing Team
FMF	Fleet Marine Force
FSSG	Force Service Support Group
FY	Fiscal Year
GOL	Carrison Operating Level
GSA	General Services Administration
HQMC	Headquarters Marine Corps
IAQ	Initial Allowance Quantity
ICP	Inventory Control Point
IMA	Intermediate Maintenance Activity
LOR	Level of Repair
LRI	Least Repairable Item
LSA	Logistic Support Analysis
MAF	Marine Amphibious Force
MCLBA	Marine Corps Logistic's Base, Albany, Georgia
MCLOR	Marine Corps Level-of-Repair
MCO	Marine Corps Order
MCPR	Marine Corps Purchase Request
MIL-STD	Military Standard

MIPR	Military Inter-Departmental Purchase Request
MO	Mount Out
MRR	Maintenance Replacement Rate
MSRT	Mean-Supply-Response-Time
MTBF	Mean-Time-Between-Failure
MTTR	Mean-Time-To-Repair
OST	Order and Ship Time
PC/SL	Procurement Cycle Safety Level
PCLT	Procurement Cycle Lead Time
PFP	Procurement Forecast Period
PMC	Procurement Marine Corps
PPD	Provisioning Program Document
PRO	Provisioning Requirements Objective
PWR	Prepositioned War Reserve
RCT	Repair Cycle Time
RR	Repair Rate
RSR	Resupply Rate
SMR	Source, Maintenance, Recoverability
TAM	Table of Authorized Material
TE	Table of Equipment
TWAMP	Time Weighted Average Month Program

I. INTRODUCTION

A. BACKGROUND

Significant growth has taken place in the number and complexity of weapon systems within the Marine Corps. Associated with this growth has been an increase in the complexity of logistics support problems and procedures.

The United States Marine Corps spent 41 million dollars in Fiscal Year (FY) 1983 for the initial provisioning support of new and existing weapon systems. In FY 84, it is expected that 35 million will be expended, and in FY 85, 40 million is expected to be spent [Ref. 1]. The figures represented here are very small in comparison to those of the other three services. The entire U.S. Marine Corps budget for FY 83 of 7.1 billion dollars representes approximately 2.5% of the entire Department of Defense budget. The Marine Corps provisioning process is miniscule compared to the Navy, Army or Air Force. Nonetheless, provisioning for Marine Corps weapon systems is equally important.

Recent initiatives within the Department of Defense and the armed services to re-orient the logistic system's support policies concentrate on the management of weapon systems on a system basis rather than the micromanagement of individual spares and repair parts. Availability of weapons systems enhances readiness.

The standard Department of Defense measure of effectiveness is operational availability (Ao). The United States Marine Corps' philosophy of readiness, and its motto of being the "first to fight" makes it extremely important to adopt the concept of operational availability. This concept is well suited to the Marine Corps and is of primary concern in sustaining combat effectiveness in the initial engagements of a hostile environment. The fact that the Marine Corps has only one Inventory Control Point (ICP) and, in theory, has total asset visibility of requirements in one place is a strong argument for adopting the operational availability concept. However, combat effectiveness generally remains dependent upon the capability of individual fighting unit managers to realistically assess their degree of readiness, to correctly identify and communicate their requirements, and to then direct managerial effort toward an optimum degree of readiness and deployability.

B. OBJECTIVE

The objective of this thesis is to provide a better understanding of some existing logistics models, specifically, with regard to utilization by the Marine Corps. At the present time, the Marine Corps does not make use of a model to examine a specific measure of effectiveness. The Marine Corps is presently developing a model for optimizing the selection of initial spares and repair parts to achieve a

maximum equipment operational availability within budget constraints. Due to the nonavailability of the model at this time, the Marine Corps Level-of-Repair model (MCLOR) output results is evaluated in this thesis utilizing the Navy Availability-Centered Inventory Model (ACIM). The feasibility of the use of the MCLOR model and the Navy ACIM model to obtain a measure of operational availability suited to the Marine Corps is explored.

Another objective of this thesis is to suggest improvements in current Marine Corps policies concerning level-of-repair, provisioning, and operational availability, and to stimulate thought and discussion within the logistics community regarding the constantly changing issues facing the Marine Corps as it prepares for the future.

C. APPROACH

In meeting the objective of this thesis, a study of the MCLOR Model and the Navy ACIM Model was conducted. Once an understanding was gained, MCLOR and actual field usage data from the AN/PRC-68 system was used to structure a numerical example. Output data from MCLOR was input to ACIM to link the two models together to determine operational availability. A sensitivity analysis was conducted to examine the trade-offs in operational availability and investment cost.

D. THESIS STRUCTURE

The structure of the thesis and the content flow is as follows:

Chapter II introduces the reader to the basic Marine Corps Provisioning process. The process described relates only to Marine ground force weapon systems. Appendices A, A1 and A2 provide formulas and examples of related segments of the process.

Chapter III provides a general description of the Marine Corps Level-of-Repair-Model (MCLOR). The purpose of the model and the cost categories and elements are briefly described. Appendices B and B1 provide the outputs, and computer routines as they relate to the model.

In Chapter IV, the basics of the Navy Availability-Centered Inventory Model (ACIM) is described. Availability measures, inputs, outputs, and model assumptions are discussed.

In Chapter V is presented the test problem and MCLOR outputs as they were subjected to ACIM. Results of desired Operational Availability (Ao) and resulting inventory are provided. The sensitivity of ACIM to changing system parameters (MTBF, MTTR, Repair Path) is discussed and results provided. Appendices C, C1 and C2 provide MCLOR input/output parameters input to ACIM, background data on SMR codes, and ACIM output data used to obtain the cost comparison curves.

Chapter VI provides a summary, conclusions and recommendations.

II. MARINE CORPS PROVISIONING

A. INTRODUCTION

The purpose of this chapter is to provide insight to the provisioning process, policies and principles of the United States Marine Corps. The provisioning process described is concerned with Marine ground forces weapons systems. The provisioning process of Marine aviation is not covered in this thesis. The United States Navy, with Marine Corps input, provides funding and the provisioning for Marine aviation.

The principle objective of provisioning is to ensure that spares and repair parts required to support and maintain new and existing end items will be available at the right time, in the right place, and in the right quantity.

The provisioning process involves risk and uncertainty. Often the equipment being introduced is for the most part new. The reliability of the repair parts usually is based on past experience with similar parts and/or on engineering and maintenance judgments provided by the contractor. Under-estimation of the range and depth of spares is often adjusted as usage data is obtained from the end user. However, equipment operational readiness or operational availability usually suffers as a result of underestimation. On the other hand, overestimating the range and depth of spare parts required causes an excessive quantity of items in the supply

system. Some of these items may never be needed. Thus the provisioning process can greatly influence the operational effectiveness and cost of equipments.

Headquarters Marine Corps (HQMC) is responsible for the overall Marine Corps provisioning process. The Marine Corps Logistics Base, Albany, Georgia (MCLBA) is tasked with the responsibility to apply the policies and principles for determining the types and quantities of spare parts required and for procuring and stocking these spare parts.

B. UNITED STATES MARINE CORPS PROVISIONING POLICY

The Marine Corps defines provisioning as:

> "The actions required to identify, select, procure and properly position in the appropriate segments of the supply system and maintenance echelons, the range and depth of repair parts tools and test equipment, and publications required to support an end item of equipment until full responsibility can be assumed by the supply system through routine replenishment" [Ref. 2].

The basic Marine Corps policy on provisioning is contained in the Marine Corps Provisioning Manual (MCO P4400.79C) dated 2 July 1976 [Ref. 2]. The manual assigns explicit responsibility for the provisioning process to Headquarters Marine Corps (HQMC), the Marine Corps Logistics Base, Albany, Georgia (MCLBA), the Fleet Marine Forces (FMF), Marine Bases and Stations, and the Marine Corps Reserve.

1. Headquarters Marine Corps (HQMC)

The Commandant of the Marine Corps (CMC) is responsible for provisioning policy within Headquarters Marine Corps (HQMC).

HQMC provides provisioning guidance, coordinates information, and provides representation at conferences and meetings relating to provisioning policies and objectives [Ref. 2].

HQMC responds to requests for guidance from MCLBA and other services and agencies of the government. Representatives from HQMC are usually invited for pre-provisioning and provisioning conferences held by MCLBA. These conferences produce the documentation and parts requirements peculiar to the provisioning process.

All funding relative to Procurement, Marine Corps (PMC) appropriations, for initial issue to the active duty Fleet Marine Forces (FMF), originates at Headquarters. A PMC allotment is regularly provided to MCLBA to finance initial stockage levels and issues.

HQMC is also involved in the coordination of all interservice agreements that arise from the provisioning efforts at MCLBA. It monitors cross service agreements on all military inter-departmental purchase requirements (MIPR'S) and Marine Corps purchase request's (MCPR'S) sent to other military services. HQMC also monitors procurement documents for end items that are managed by the Defense Logistics Agency (DLA) and the General Services Administration (GSA).

HQMC provides MCLBA with the current Provisioning Program Document (PPD), the Procurement, Marine Corps (PMC) shopping list for the program, budget, and apportionment years. This list notifies MCLBA that certain end items are

to be procured during the current fiscal year. This is the first indication that research and development work has been successful, and that the Marine Corps plans to introduce a new system or modify an existing system. The following information must be furnished, as appropriate, on a timely basis, during the planning, programming and budgeting cycle to be used in conjunction with PPD and PMC shipping list data for preparation of budget estimates:

(1) Total quantity to be procured.

(2) Maximum support quantity.

(3) Planned in-use quantity.

(4) Marine Corps organizations which will employ the equipment and the quantity to be employed by each organization.

(5) Life expectancy.

(6) Standardization status.

(7) What equipment is to be replaced, if any.

(8) Quantity of new end items requiring drawdown initial issue.

(9) End item essentiality (combat-essential, mission support, critical low density).

(10) End item contract award date, if available.

(11) Planned first article approval date.

(12) Planned in-service date. [Ref. 2]

Headquarters includes in the budget, under the PMC appropriation, funds to finance the complete initial issue to the active duty FMF. Funding is accomplished through the regular PMC allotment to the Marine Corps Logistics Base,

Albany. Applicability of funds and guidance relative to accounting and reporting will be provided with the allotment.

2. Marine Corps Logistics Base, Albany (MCLBA)

MCLBA manages the Marine Corps provisioning program. Detailed functions performed by MCLBA are given in MCO P4400.79C [Ref. 2]. The primary fucntions are to conduct meetings; develop schedules and procedures; obtain, monitor and review data and documentation; collect, collate and evaluate essential empirical data; assign key codes; and determine the range and quantity of initial stockage items [Ref. 2].

MCLBA plays host to pre-provisioning and provisioning team conferences when the Marine Corps is the material manager. The following provisioning goals are expected to be achieved at the various meetings and conferences:

A. Determine logistics provisioning requirements.

B. Establishing the organizational level of the need.

C. Setting levels and length of use before replacement is required.

D. Funding and acquiring the appropriate item.

The provisioning manual lists data which should be collected, evaluated, and stored because of its significance in requirements determination. MCLBA takes the necessary action in each of these areas:

A. Procurement leadtime.

   1. Administrative leadtime.

   2. Production leadtime.

B. Fourth echelon secondary repairable repair data.

C. Fifth echelon secondary repairable repair need.

D. Order and shipping time.

   1. User, Continential United States and Overseas (CONUS).

   2. Service Battalion, 1st Marine Brigade CONUS and Overseas.

   3. Forces Service Support Group - CONUS and Overseas.

E. Peacetime and combat maintenance replacement rates.

   1. Combat and peacetime failure rates.

   2. Maintenance replacement rates.

   3. Repair rates.

   4. Repair cycle time.

   5. Order and shipping time.

   6. Washout rates (BCM rate).

   7. Economic repair (batch) quantity.

   8. Time in repair.

   9. Repair interval.

F. Source, maintenance, and recoverability (SMR) codes.

G. Criticality codes.

H. Resupply rates. [Ref. 2]

Once the preliminary functions identified above have been completed, MCLBA determines the stockage levels required to support the end items of equipment [Ref. 2].

The computation of requirements by the Marine Corps is filled with many risks and uncertainties. It is difficult to be accurate when there are so many variables influencing the outcome.

C. THE PROVISIONING MODEL

The Department of Defense established the basic objectives and policies for initial requirements determination in Department of Defense Instruction 4140.42 [Ref. 3]. Four events are identified as crucial to the development for initial requirements:

- development of program data for initial requirements determination.
- initial requirements computation policy.
- the decision to stock or not to stock at the wholesale level based on guidance provided in enclosure two of DODI 4140.42 and retail level stockage decisions made in accordance with DOD service component developed rules.
- the demand development period computation policy.

The instruction provides quantitative criteria and models to assist the military service in making better initial provisioning stockage decisions.

The implementation of DODI 4140.42 and the mechanics of requirements computations are the responsibility of MCLBA in the Marine Corps. The computation process begins with the selection of parts and proceeds through the individual computation formulas for the initial stockage levels, initial allowance quantity and prepositioned war reserve quantity.

The basic model that the Marine Corps uses for initial requirements determination of repair parts is derived from Department of Defense Instruction 4140.42 [Ref. 3] and comprises 36 formulas and over 100 variables. The formulas were developed to calculate the number of spares (repairables)

and repair parts (consumables) needed to support an end item during the Data Development Period (DDP). A basic assumption of the models is that the DDP will last a maximum of two years.

The basic equation states that a quantity (Q) of spares or repair parts is the product of a replacement factor per end item per year (A), times the number of such parts contained in an end item (B), times the number of end items supported (C), and times a support interval (D). The equation then takes on the following form:

$$Q = A \times B \times C \times D \tag{2-1}$$

The basic variables found in the formulas are production leadtime, authorized day level, repair rate, repair cycle time and peacetime/combat replacement factor. The Marine Corps uses separate formulas which are applicable to system stock, initial allowance quantity and prepositioned war reserve (PWR).

The system stock strata consists of a procurement cycle safety level quantity (PC/SL) and procurement cycle leadtime quantity (PCLT). The initial allowance quantity (IAQ) contains a garrison operating level (GOL) and a mount out level (MO). The prepositioned war reserve (PWR) has material for the active forces and all requirements for the inactive mobilization forces (4th Marine Division/Wing Team) [Ref. 2].

1. Initial System Stock

The levels of initial system stock for Marine Corps managed items vary by provisioning project, procurement leadtime, washout (Beyond capability of Maintenance) rates, and whether an item is new or already exists within the Marine Corps Supply System. The computed quantities for system stock must support the entire density of end items in service until actual demands from the end user have been generated to establish a routine replenishment rate. The provisioning requirements objective for the initial system stock levels of consumables and repairable parts is equal to the procurement cycle leadtime quantity.

The first step in the computation of initial system stockage levels is the development of program data. The provisioner develops an initial program forecast period (PFP). The PFP is smoothed for demand forecasting into a Time Weighted Average Month Program (TWAMP). The TWAMP is the average number of monthly operational units of a program through a program time base.

The TWAMP value is used to compute a PC/SL quantity and a PCLT quantity. The sum of these two quantities is the provisioning requirements objective (PRO) for an initial stockage level. Appendix A provides the formulas and an example of both consumable and repairables.

2. <u>Initial Allowance Quantity (IAQ)</u>

The initial allowance quantity (IAQ) is the range and quantity of repair parts required for stockage at the using and support levels. IAQ consists of a garrison operating level (GOL) and a mount out level (MO). When an organization is to be committed to combat, it will use the mount out. Appendix A1 provides the formulas and examples of consumables, repairables and the mount out.

3. <u>Prepositioned War Reserves (PWR)</u>

The prepositioned war reserve (PWR) supplies the active forces and all requirements for the inactive mobilization forces (4th Marine Division/Wing). The PWR assets are held at Albany, Georgia and Barstow, California, and are available when required. Appendix A2 provides the formulas and examples for consumables and repairables.

III. THE MARINE CORPS LEVEL-OF-REPAIR MODEL (MCLOR)

A. INTRODUCTION

The Marine Corps Level-of-Repair (MCLOR) model is a computer program which is an adaptation of the Navy Level-of-Repair (LOR) model - MIL-STD-1390B [Ref. 4]. Appendix D of MIL-STD-1390B provides the detailed analytical computations for determining the cost factors applicable to repair or discard decisions for a particular system.

The purpose of the MCLOR is to provide cost and time estimates in a meaningful manner in order to facilitate decisions on maintenance policies for systems at various stages of development. Presently, the computer program is installed at Headquarters Marine Corps; Marine Corps Logistics Base, Albany, Georgia; and at the Johns Hopkins Applied Physics Laboratory, Maryland. The model is programmed in Fortran IV G to operate in batch mode on the IBM 360/370 series computer. Currently, the only operational model is located at the Johns Hopkins Applied Physics Laboratory.

Detailed instructions for the use of the model are found in the "System Users Manual" [Ref. 5], "Program Maintenance Manual" [Ref. 6], and the "Computer Operations Manual" [Ref. 7].

B. THE MODEL

The Marine Corps Level-of-Repair model provides a technique to derive optimum decisions from alternative maintenance policies. The decisions aid in identifying the lowest cost alternative for maintenance support of a specific hardware item.

For Marine Corps operations, military maintenance is performed at these levels:

- Organizational level (1st and 2nd echelons)
- Intermediate level (3rd and 4th echelons)
- Depot level (5th echelon)

Repair of items may take place at several of these levels depending upon the complexity of the equipment and the skills required to repair. The MCLOR provides four distinct levels:

- Organizational (0)
- 3rd echelon (3)
- 4th echelon (4)
- Depot (D)

If multiple level of repair is authorized and repair cannot be accomplished at the lowest capable echelon, the item may be evacuated to the prescribed next higher echelon. If repair cannot be accomplished at the next higher echelon, the item is discarded. The number of next higher echelons is dependent upon the repair path being evaluated. For example, the repair path 034D reflects three higher echelons beyond the first point of repair which is organizational (0) in this example.

The MCLOR model computes life support cost for four equipment indenture levels: system, unit, assembly, and Least Repairable Item (LRI). Individual data elements are required for each indenture level consisting of six cost categories and 12 cost elements. The life support cost is a summation of the 12 cost elements.

COST CATEGORY	COST ELEMENT
Inventory	Item entry and retention Inventory cost Repair material cost Packaging and transportation
Support	Support equipment only Support of support equipment
Space	Inventory storage space cost Support equipment space cost Repair work space cost
Labor	Labor cost
Training	Training cost
Documentation	Documentation cost

Inventory, inventory storage space, transportation, material, labor, and training are variable costs and are directly proportional to the number of repairs of an item. Variable costs also include item entry and retention but are independent of the number of repairs. Repair work space, support equipment, support equipment space, support equipment maintenance, and support equipment documentation are fixed costs. These costs are incurred even if only one item that uses a fixed asset is repaired. The model allows for two types of analysis:

1. Life support cost of maintaining a system
2. Optimum repair path

A third run option is available to determine the sensitivity of LOR life support cost to input parameter variations.

1. Inputs

The model utilizes two basic types of input data which require up to 70 inputs for each type. System inputs are data common to the system being evaluated. The item input data provides information pertinent to those items that comprise the system. A separate item input is required for each indenture level.

2. Outputs

The MCLOR provides a repeat (echo) of all input data and creates three major reports which are determined by (1) snapshot vs optimization mode, (2) sensitivity analysis, (3) allocation vs non-allocation, and (4) user option. The three major outputs are as follows:

A. System summary

B. Item summary

C. Item breakdown

The output reports are shown in Appendix B.

C. PROGRAM OPERATION

The MCLOR is composed of 20 routines, a main program, a BLOCK DATA routine and 18 subroutines. The 18 subroutines identify the relationships among the routines. A list of the routines is provided in Appendix B1. A flow diagram of the model is shown in Figure III-1.

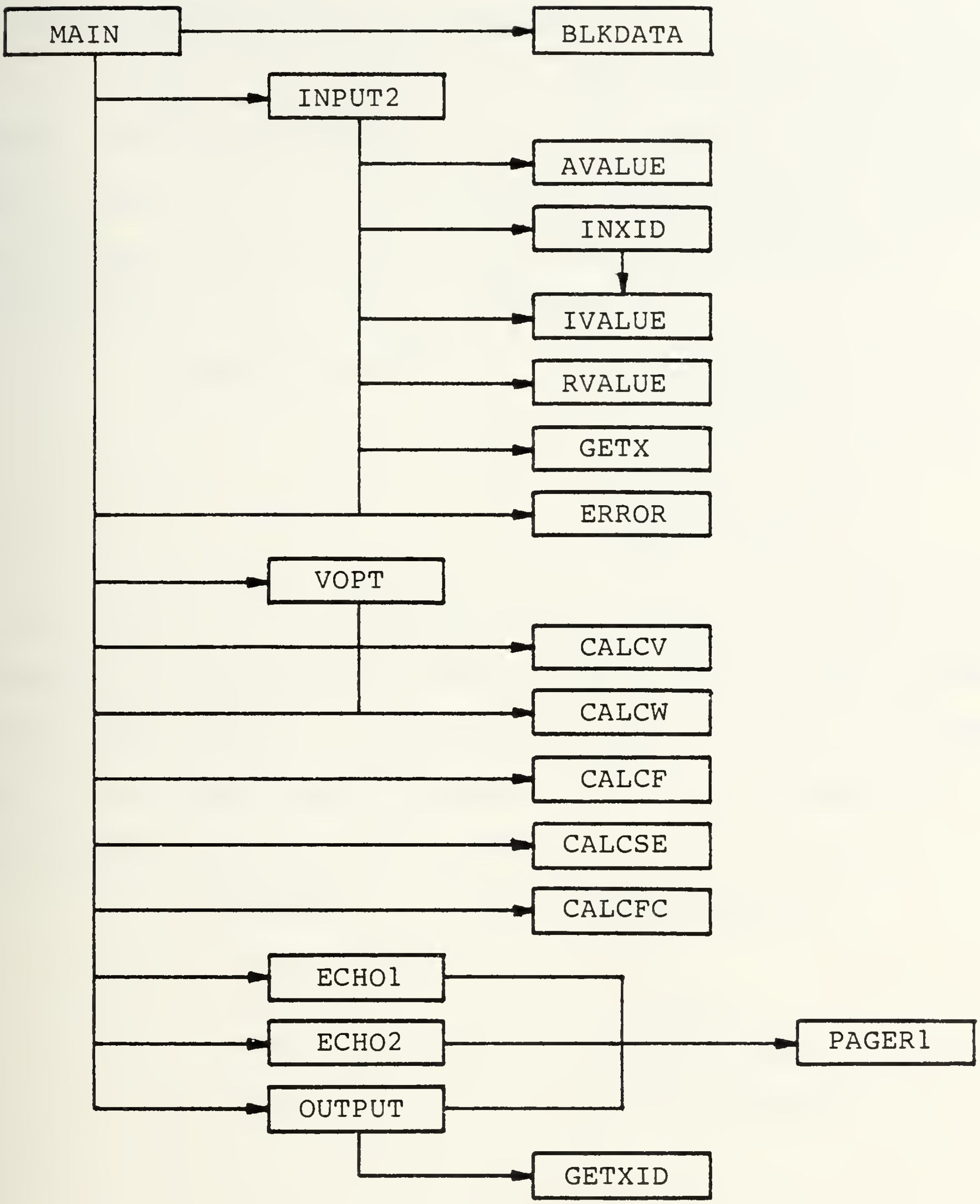


Figure III-1. MCLOR Flow Diagram

D. GENERAL DESCRIPTION OF THE MODEL

As stated in section 3.A, the model determines the life support cost for maintaining a failed item and provides the optimum repair flow to the point of complete repair or discard. The equipment indenture levels are basic partitions for segregating the cost and are listed below:

INDENTURE LEVEL	DESCRIPTION
0	System
1	Unit
2	Assembly
3	LRI

An example of the numerical relationships that exist is provided by illustrating an M60-A1 tank as a system composed of four basic units. It is important to note that the breakdown of the system is at the discretion of the analyst in order to provide more or less detail:

UNIT NO.	DESCRIPTION
1	Hull
2	Turret
3	Power train
4	Fire control

The units are then subdivided into assemblies:

UNIT NO.	ASSEMBLY NO.	DESCRIPTION
1	0	Hull
1	1	Suspension
1	2	Electrical
2	0	Turret
2	1	Radios
2	2	Hatches
3	0	Power train
3	1	Engine
3	2	Final drive
4	0	Fire control
4	1	Main gun (M68)
4	2	Breech

The assemblies can then be broken down into least repairable items:

UNIT NO.	ASSEMBLY NO.	LRI NO.	DESCRIPTION
1	1	0	Suspension
1	1	1	Track
1	1	2	Torsion bar
1	1	3	Housing seals
1	2	0	Electrical
1	2	1	400 amp relay
1	2	2	Batteries
1	2	3	Wiring harness

The relationship of the numbering sequence is expressed in more direct terms by the following example:

ITEM NO	ITEM TYPE	DESCRIPTION
1.0.0.	Unit	Hull
1.1.0.	Assembly	Suspension
1.1.1.	LRI	Track
2.0.0.	Unit	Turret
2.1.0.	Assembly	Radio
2.1.1.	LRI	CVC helment

Any numbering sequence may be used to identify the indenture levels of the model as long as the number of digits do not exceed eleven. Logistic Support Analysis (LSA) control numbers are often used in lieu of the above example.

1. <u>Repair Process</u>

"Repair of any item (such as a unit) which contains sub-items (assemblies) implies that work is performed to identify the failed sub-item and that repair is effected by sub-item removal and replacement." [Ref. 4]

An assumption of the MCLOR model is that items always flow up the maintenance chain. That is, an item failure cannot be diagnosed at a higher echelon and be sent back to a lower echelon for repair. The Marine Corps utilizes a four echelon maintenance concept. The MCLOR allows a choice or combination of all these repair points. The repair points are assigned codes which specify a repair path for each item in the system. The codes assigned are as follows:

CODE	DESCRIPTION
0	Organizational level
3	Intermediate (3rd echelon)
4	Intermediate (4th echelon)
D	Depot level
X	Discard without attempting repair

A combination path of "0-4-" implies that simple maintenance and repair can be performed at organizational maintenance. The 3rd echelon does not have the authorization or capability to repair the item. The 4th echelon has complete repair capability and any item beyond the capability of repair at that point will be washed out.

The sixteen listed repair paths are as follows:

CASE	REPAIR PATH
1	---D
2	--4-
3	-3--
4	0---
5	03--
6	0-4-
7	0--D
8	-34-
9	-3-D
10	--0D
11	034-
12	03-D
13	0-4D
14	-34D
15	034D
16	Discard

2. Discard

The MCLOR has the option of discard as an alternatative to repairing the item. MCLOR discard may be defined as implicit or explicit. Implicit discard was demonstrated in section 3.D.1, by repair path "0-4-", in which any item beyond repair at 4th echelon is automatically washed out. Explicit discard is identified by the LOR code "X" in the position where the normal repair path code would be given (0,3,4,X).

IV. ACIM, AN AVAILABILITY-CENTERED INVENTORY MODEL

A. INTRODUCTION

The purpose for inventories of spare and repair parts is the readiness and sustainability of our military forces. The Department of Defense (DOD) must achieve this purpose by meeting the following criteria [Ref. 8]:

* The goals to achieve readiness and sustainability must be readily identifiable at specified costs.

* Requirements for spares and repair parts should be computed to provide specified levels of readiness and sustainability at least cost.

* The least cost method of meeting readiness and sustainability through spares and repair parts must be identified by program and budget documentation.

* The logistic system must be viewed as an integrated whole.

Availability models are now able to link inventory decisions directly to weapon system availability goals. This linking process requires accurate data on component characteristics and end item configuration, but is considered to be a promising approach for relating Department of Defense criteria to military readiness and sustainability.

The Availability-Centered Inventory Model is a computer program which provides a procedure for determining the stockage requirements for all items of an equipment in a multi-echelon supply support system at designated locations. The model also provides a technique by which comparisons can be made between the ACIM stockage policy and a policy currently in existence.

B. AVAILABILITY MEASURES

The Availability-Centered Inventory Model computes stock levels such that a desired operational availability may be achieved at minimum cost. The expected operational availability is represented by the symbol "Ao" and is found by the general formula expressed in Figure IV-1 and is more commonly expressed by the formula:

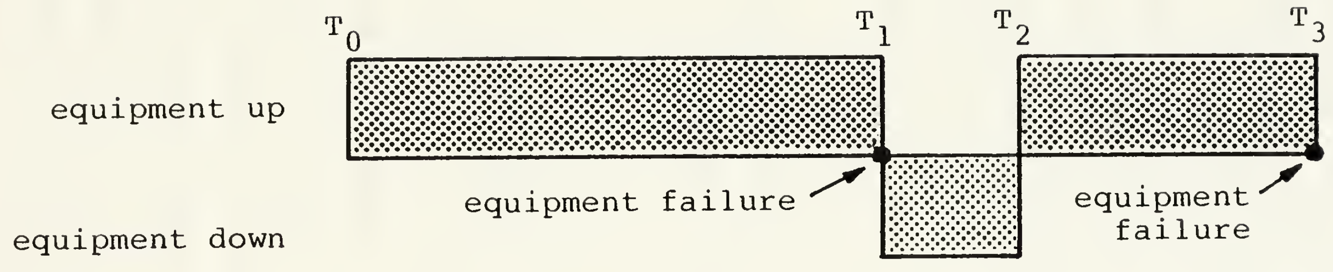
$$Ao = \frac{MTBF}{MTBF + MTTR + MSRT} \qquad (4\text{-}1)$$

Uptime is defined as the Mean-Time-Between-Failures (MTBF) and downtime is a combination of Mean-Time-To-Repair (MTTR) and Mean-Supply-Response-Time (MSRT). "Based on this definition, operational availability is the fraction of time, on the average, that the equipment is in an operable condition or can be interpreted as the probability that the equipment is in an operable condition at a random point in time. The MTBF and MTTR are held constant in the model while the MSRT is dependent upon stockage levels and is therefore changed by the model to achieve the desired Ao" [Ref. 9].

C. ACIM BACKGROUND AND SCOPE

The Availability-Centered Inventory Model is the result of an in-depth study and analysis of previous inventory models such as METRIC and MODMETRIC [Ref. 10]. The first use of ACIM provided comparisons with other Navy stockage policies such as Coordinated Shipboard Allowance List (COSAL). The COSAL policy indicates the items, including the quantity of each, which a

$$Ao = \frac{\text{uptime}}{\text{uptime + downtime}}$$



T = time

Figure IV-1. Operational Availability (Ao) [Ref. 9]

ship should have on hand to achieve a selfsupporting capability for an extended period. The intent of COSAL is to provide a 90 day level of support for both planned and corrective maintenance actions [Ref. 11]. The ACIM model as we know it today is the result of additional redevelopment and refinement. The Availability-Centered Inventory Model was approved by the Chief of Naval Operations in March 1981 [Ref. 12]. Its primary use is to determine stockage quantities for equipments with a history of low operational availabilities in which difficulties were experienced in obtaining spares and repair parts from normal supply channels. Initially, ACIM was limited to a single echelon, but it was later refined to include multi-echelon applications in order to increase support responsiveness for a variety of equipments.

The model is capable of computing stockage levels for all parts contained within the indenture levels of an equipment. The stockage levels calculated include all ships and stations, intermediate maintenance activities, and depots that support the equipment. The number of items and locations considered is limited only by the capacity of the computer used. Items considered by the model may be repairable, consumable or any mix thereof. Each appearance of an item in the input is treated as unique insofar as operations and stockage requirements are concerned.

ACIM is capable of recognizing interrelationships of parts in a hierarchical breakdown of the equipment and the

interrelationships among the activities in a multi-echelon supply support system, but these features need not be fully exercised in a given application. In considering shipboard stockage requirements only, two sets of levels are produced by each run of the model. A comparison policy is calculated for policies currently used such as the COSAL policy. The particular comparison policy to be used is determined by the specified input factor. ACIM calculates stock levels and inventory performance results along with the comparison policy. This allows analysis of the new policy versus current Navy policies in use.

D. ACIM DESCRIPTION

ACIM consists of three programs that operate in sequence (Figure IV-2). The preprocessor program calculates stock levels according to the designated comparison policy, or reads in stock levels if calculated by policies/procedures outside the model. If only Coordinated Shipboard Allowance Lists are being computed, then a Mean Supply Response Time (MSRT) is determined for each item. The MSRT values and stock levels are passed to the other programs of the model for further use.

The main program of the model calculates levels according to ACIM. The levels are determined by a mathematical procedure which is iterative in nature, with each iteration finding the item and stockage location for which an additional unit of stock will yield the largest increase in operational availability at the user site per dollar invested. This process

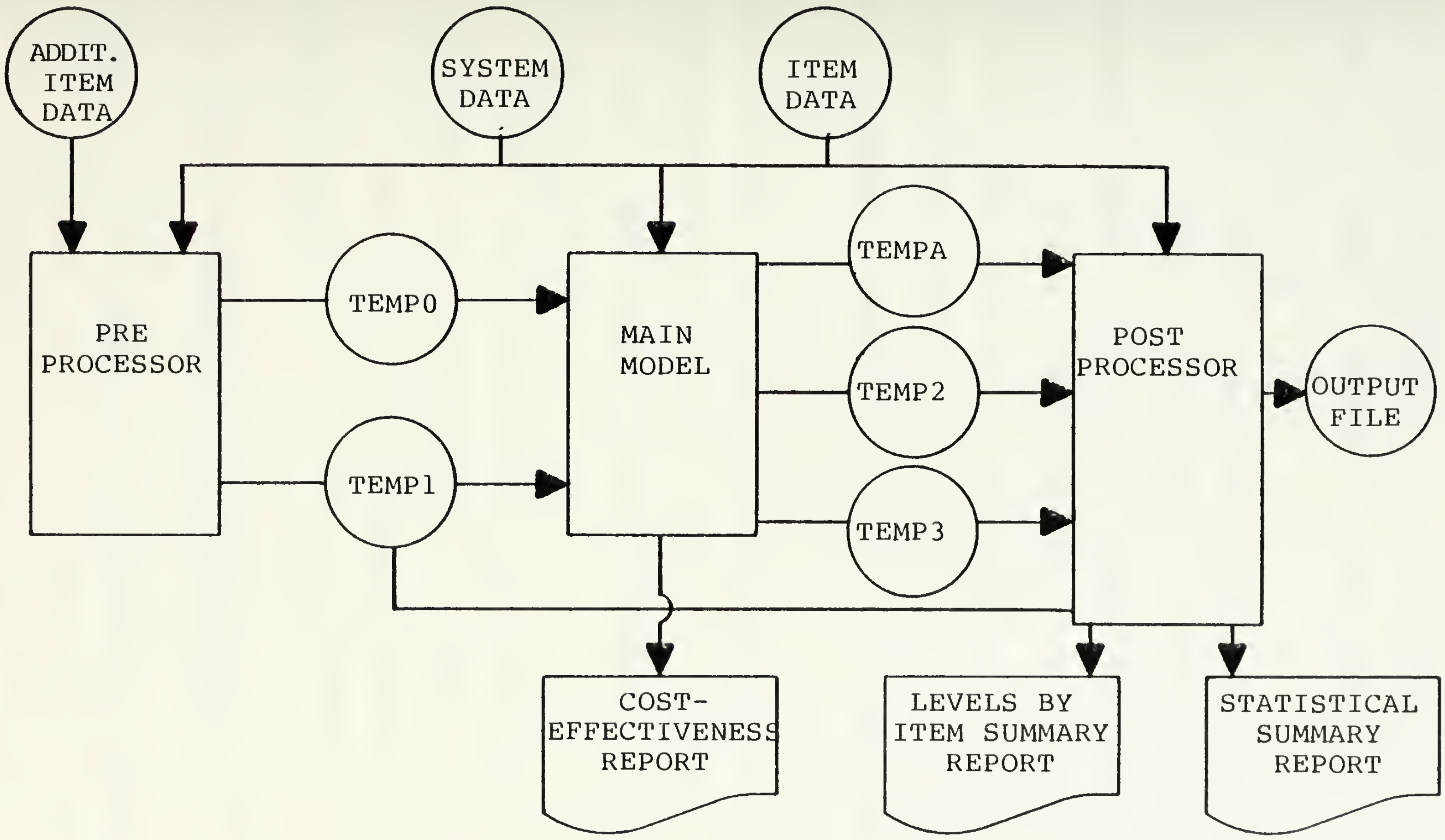


Figure IV-2. ACIM Description [Ref. 9]

continues until an availability or investment goal is obtained thus providing specific stockage levels which represent the results of the policy.

As the main program continues this iterative procedure, intermediate outputs are developed in the form of a cost-effectiveness report. Data may be extracted from the report to construct a cost-effectiveness curve (Figure IV-3). Each point on the curve represents the availability per the investment determined by the selected stock levels. A saturation point is ultimately reached where further investment contributes very little to operational availability. The cost-effectiveness report also shows the availability/investment relationship for the comparison policy utilized. This is plotted as a point and is normally below the optimal cost-effectiveness curve.

1. Assumptions

The Availability-Centered Inventory Model is subject to many assumptions and limitations with respect to its formulation and solution procedure. The principal assumptions are:

* Items are organized for a system/equipment in a top-down indenture level.
* The items of an equipment considered by the model may be repairable, consumable, or any mix thereof.
* Multiple use of a specific item within a given higher assembly is represented only once in the breakdown.
* Supply/repair facilities are organized in a hierarchical structure according to supply maintenance flows.
* Mean-time-to-repair and mean-time-between-failure are given as inputs to the model.

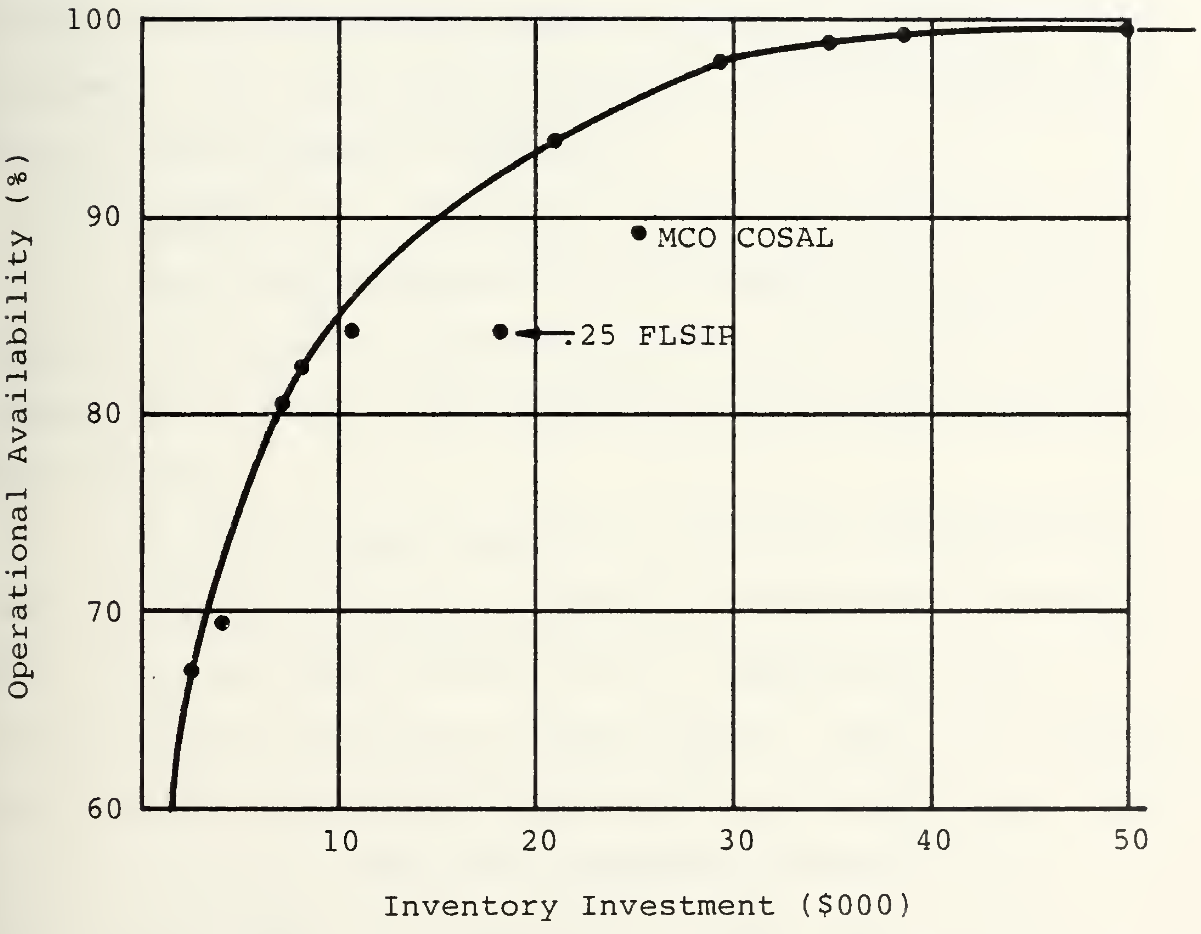


Figure IV-3. Cost-Effectiveness Curve

* One-for-one ordering (S-1,S) Inventory Policy.
* No lateral resupply.
* Demands are Poisson distributed.

2. Inputs

System-related and item-related input data are the two main types of data used by ACIM. The system-related data are contained in a file composed of records in three different formats which given policy parameters, default values, model options, and definition of sites in support/operation of the equipment. The item-related data are defined by individual parts of the equipment (Table IV-I).

3. Outputs

Stock levels computed by the preprocessor and main programs are passed to the postprocessor which is the final program of the model. The output of this program consists of three reports.

The first report produced is the cost-effectiveness report which gives values for initial and maximum attainable Ao for each user site (Table IV-II). The initial Ao is computed based on initial stockage levels. When the optimization mode has been designated, there is an assumed zero stockage level for all items. The maximum attainable Ao is calculated assuming that sufficient spares are available in the system so that no equipment downtime occurs due to supply shortages.

TABLE IV-I

ITEM RELATED DATA

```
A MC LOR STUDY                  .19 .90 9999999    1          09              180   .190
L MC DEPOT ALBGA 1 D X     180          1    0 50    0
L MC FSSG CLNC   2 I X X    90     30   1    0 50    0
L MC 2MARDIVCLNC 3 O                    1  840 50    0      .90
L MC 2MARDIVDEPL 3 O X X    30      7   1  282 50    0      .90

//GO.DATA   DD
I10000      1 AN/PRC-68    9G     1                         1300
I10100      2 IF/AF        9G     1      15800      OFF     0160    1  1
I10200      2 ANT.CPLR     9G     1       6100      OZZ     0060    1  1
I10300      2 VCO          9G     1      10600      OZZ     0070    1  1
I10400      2 FILTER/IF    9G     1       9100      OZZ     0020    1  1
I10500      2 CONVERTER    9G     1      11800      OZZ     0120    1  1
I10600      2 MOD/MXR      9G     1      27300      OZZ     0040    1  1
I10700      2 SYNTHSZR     9G     1      24200      OFF     0300    1  1
I10800      2 XMTR         9G     1      17900      OZZ     0020    1  1
I10900      2 FRAME/PANEL  9G     1      39700      OFF     0500       1

//GO.JCARD   DD
J10100     30    90      .10     461    37     0     65
J10200     30    90     1.00     427    37     0     65
J10300     30    90     1.00     461    37     0     65
J10400     30    90     1.00     237    19     0     33
J10500     30    90     1.00     461    37     0     65
J10600     30    90     1.00     461    37     0     65
J10700     30    90      .10     461    37     0     65
J10800     30    90     1.00     427    37     0     65
J10900     30    90      .10     427   102     0      0
```

TABLE IV-II

COST EFFECTIVENESS REPORT

ITEM	COST	SITE	LEVEL	MSRT	USER	ASUBO	COMCOST	CODE	CONTROL
10	397	3	2	1.641	3	0.555368	18869	U	2.416978
2	158	4	3	1.712	4	0.781771	19027	U	2.011796
6	118	2	9	1.677	4	0.784874	19145	U	1.711618
4	106	2	6	1.617	4	0.790346	19251	U	1.677172
7	273	2	4	1.453	4	0.805676	19524	U	1.617083
8	242	4	4	1.149	4	0.835736	19766	U	1.453074
2	158	2	6	1.129	4	0.837762	19924	U	1.148956
3	61	2	6	1.104	4	0.840394	19985	U	1.129242
10	397	4	5	0.730	4	0.881016	20382	U	1.103768
9	179	2	3	0.865	3	0.684281	20561	U	0.945295
10	397	3	3	0.585	3	0.746919	20958	U	0.865182
6	118	1	7	0.657	4	0.889366	21076	U	0.674879
8	242	2	7	0.627	4	0.892931	21318	U	0.657419
7	273	4	2	0.467	4	0.912053	21591	U	0.626839

0.9000 AVAILABILITY TARGET REACHED AT SITE 4

2	158	3	2	0.338	3	0.812304	21749	U	0.393172
4	106	3	3	0.306	3	0.821819	21855	U	0.338441
7	273	3	2	0.229	3	0.845261	22128	U	0.305845
10	397	3	4	0.149	3	0.870836	22525	U	0.228668
8	242	3	3	0.107	3	0.885058	22767	U	0.149208
5	91	3	2	0.092	3	0.890332	22858	U	0.107008
6	118	3	5	0.073	3	0.896695	22976	U	0.091701
3	61	3	3	0.067	3	0.898954	23037	U	0.073476
9	179	3	2	0.052	3	0.904395	23216	U	0.067065

0.9000 AVAILABILITY TARGET REACHED AT SITE 3

TARGET/MAXIMUM AVAILABILITY REACHED AT ALL SITES.

The second output report (Table IV-III) produces a line of data for each item with relevant input factors and the levels calculated for the comparison policy and ACIM. The third report (Table IV-IV) provides overall performance measures for the comparison and availability-centered policies such as the range of items stocked, investment, expected fill rate, and expected operational availability.

Each of the above reports is produced for each different stockage site. The data file produced contains a record for each item. This file contains the item's input data record and the stock levels computed by the model.

The model is programmed in PL/1 and can be implemented on most computers, ranging from desk top microcomputers to the largest available. Complete details of the model and mathematical descriptions are contained in the ACIM Handbook [Ref. 12].

TABLE IV-III

LEVELS BY ITEM SUMMARY REPORT

ITEM	REFERENCE NUMBER	IND	PART NUMBER & NOMENCLATURE	COG	POP	UNIT COST	SM&R	BRF	MRU	MEC	OVR C	OVR A	O&ST	COMPARISON MSRT	COMPARISON QTY	ACIR MSRT	ACIR QTY
1	10000	1	AN/PRC-68	9G	1	0.00		0.1900	1	0		0	0.00	0.0000	0	0.0000	0
2	10100	2	IF/AF	9G	1	158.00	OFF	0.0270	1	1		0	0.00	0.0000	461	179.9999	0
3	10200	2	ANT.CPLR	9G	1	61.00	OZZ	0.0090	1	1		0	0.00	0.0000	427	77.8645	3
4	10300	2	VCO	9G	1	106.00	OZZ	0.0100	1	1		0	0.00	0.0000	461	86.1842	3
5	10400	2	FILTER/IF	9G	1	91.00	OZZ	0.0030	1	1		0	0.00	0.0000	237	94.4435	1
6	10500	2	CONVERTER	9G	1	118.00	OZZ	0.0200	1	1		0	0.00	0.0000	461	68.2953	7
7	10600	2	MOD/MXR	9G	1	273.00	OZZ	0.0060	1	1		0	0.00	0.0000	461	81.9915	2
8	10700	2	SYNTHSZR	9G	1	242.00	OFF	0.0440	1	1		0	0.00	0.0000	461	112.7108	1
9	10800	2	XMTR	9G	1	179.00	OZZ	0.0030	1	1		0	0.00	0.0000	427	94.4435	1
10	10900	2	FRAME/PANEL	9G	1	397.00	OFF	0.0700	1	1		0	0.00	0.0000	427	134.4930	1

TABLE IV-IV

OVERALL PERFORMANCE MEASURES

	COMPARISON POLICY	ACIR POLICY
TOTAL NUMBER OF ITEMS	10	10
# DELETED BY OVERRIDE CODE X	0	0
# EXCLUDED BY OVERRIDE CODE Y	0	0
# EXCLUDED BY SM&R CODES	0	0
NUMBER OF STOCKAGE CANDIDATES	10	10
# ITEMS STOCKED	9	8
# ITEMS NON-STOCKED	1	2
PERCENT STOCKED	90.00	80.00
# UNITS STOCKED	3823	19
INVESTMENT ($000)		
STOCKED	707.083	2.782
NON-STOCKED	0.000	0.158
PERFORMANCE		
FILL RATE	1.000	0.500
EXPECTED UNITS-SHORT	3823.000	32.335
BACKORDER-DAYS	-0.004	3218.326

V. NUMERICAL EXAMPLE

A. INTRODUCTION

In this chapter the ability of ACIM to obtain a desired level of Operational Availability (Ao) for the Marine Corps at minimum investment is demonstrated through the use of a numerical example. The input data for the numerical example is based upon data provided by Headquarters, Marine Corps and field usage data for sensitivity analysis.

The highlights of provisioning, MCLOR and ACIM are recapped briefly as follows:

PROVISIONING

* Provides stockage decisions in advance of actual demand to provide a weapon system with adequate support until replenishment operations can take over.

* Initial estimates are, by necessity, based upon certain assumptions and available data.

* Provides data for the purpose of presenting a budget request.

MARINE CORPS LEVEL-OF-REPAIR (MCLOR)

* Provides cost and time estimates in a meaningful manner in order to facilitate decisions on maintenance policies.

* Affects design and development decisions early in the acquisition process.

* Identifies the least-cost alternative for maintaining a failed hardware item.

* Recommends an optimal repair path.

* Aids in analysis of the life cycle cost of maintaining the system.

AVAILABILITY-CENTERED INVENTORY MODEL (ACIM)

* Computes a stock level at designated locations.
* Computes an equipment operational availability for a given inventory investment, or the inventory investment required to meet a given operational availability.

1. Chapter Description

The process flow of this chapter is divided into three major areas of discussion and is illustrated in Figure V-1.

* Linking Process
* Repair Path Sensitivity Analysis
* Sensitivity Analysis on the Mean-Time-Between-Failure and the Mean-Time-To-Repair.

The linking process indicates how the MCLOR model, the system example, Marine Corps policy on categories of operational readiness versus investment selected, system characteristics, and input variables as they relate to the ACIM model are linked together.

Repair path sensitivity analysis is concerned with the level of repair (organizational, intermediate, depot) and its effect on the system concerning investment and operational availability.

The final section of the chapter includes a sensitivity analysis on the Mean-Time-Between-Failure and Mean-Time-To-Repair and their effect upon operational availability as well as the associated dollar cost to achieve a specified operational availability.

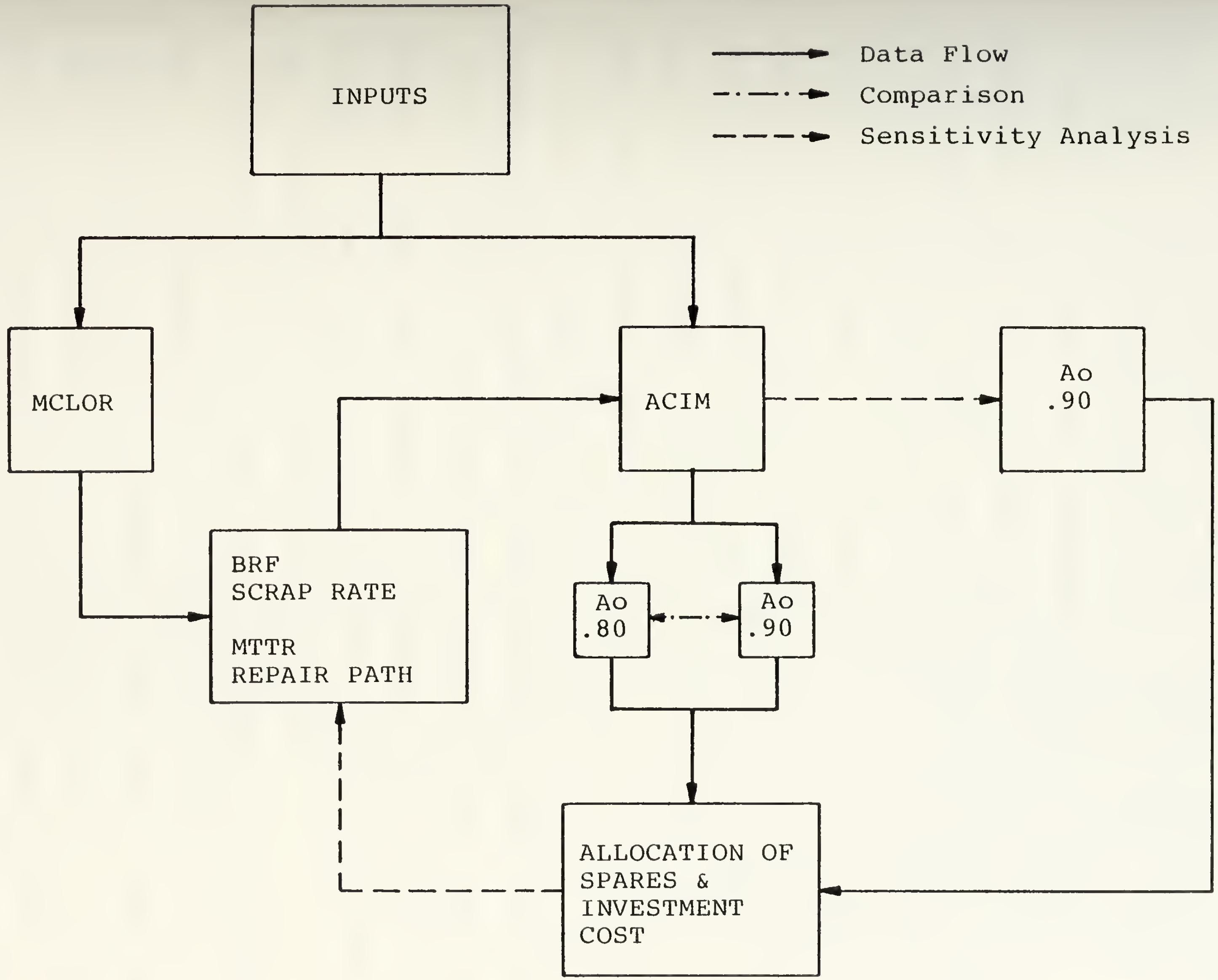


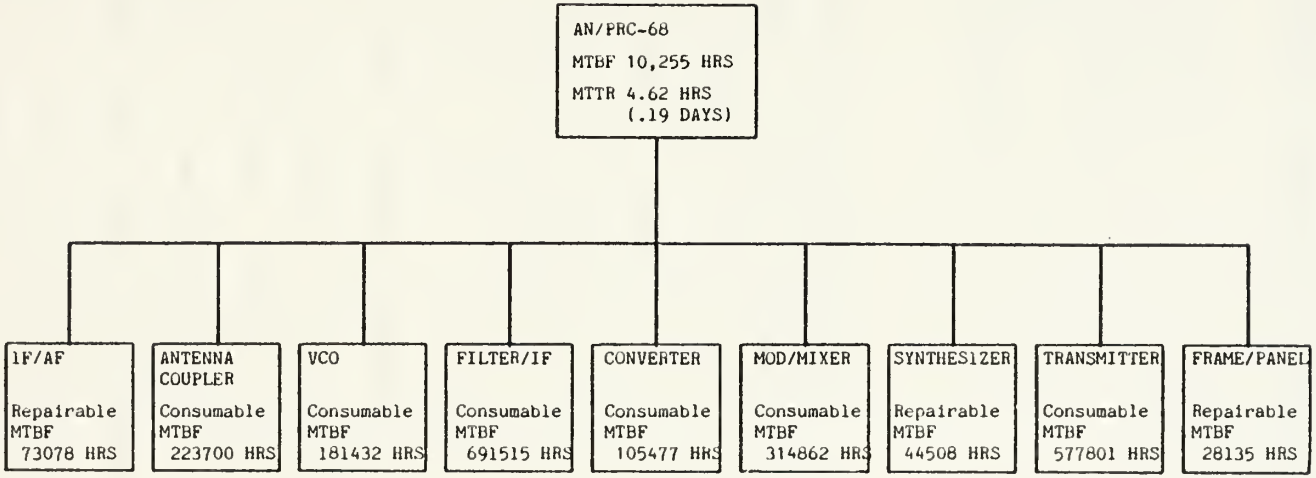
Figure V-1. Process Flow

B. THE LINKING PROCESS

The Marine Corps Level-of-Repair Analysis (MCLOR) input and output data utilized to exercise the ACIM model were obtained from the Evaluation Research Corporation, Vienna, Virginia, via Marine Corps Headquarters and are shown in Appendix C [Ref. 13]. The equipment for which the LOR analysis was performed is a simple, one indenture level radio (AN/PRC-68). The radio is a hand-held item utilized at the Marine Corps Infantry Squad Level. It is considered a critical item of equipment for the purpose of coordination and communication within small tactical units. The AN/PRC-68 is composed of nine line repairable items (LRI's) of which three are repairable and six are consumable as dictated by the MCLOR analysis.

Figure V-2 shows the system breakdown and system Mean-Time-Between-Failure, system Mean-Time-To-Repair, and repairable/consumable status. The equipment has been in the Fleet Marine Force less than one year and is presently used by Second Marine Division, Camp Lejeune, North Carolina. The Marine Corps is the item manager for the Army and the Navy.

The MCLOR analysis shows 4960 equipments in the system, but only 1122 AN/PRC-68's are assigned to Marine units in Second Marine Division as directed by the table of equipment [Ref. 14]. The radios are authorized for use by all Second Division Infantry Battalions and certain combat support organizations. Table V-I shows the allowance of radios to the Second Division units. For the purpose of the numerical



NOTE: MTBF's are given values based on system specifications and have decreased about 10% since the equipment has been in the field.

Figure V-2. System Breakdown

example, a modified organization structure was derived from Table V-I and is illustrated in Figure V-3.

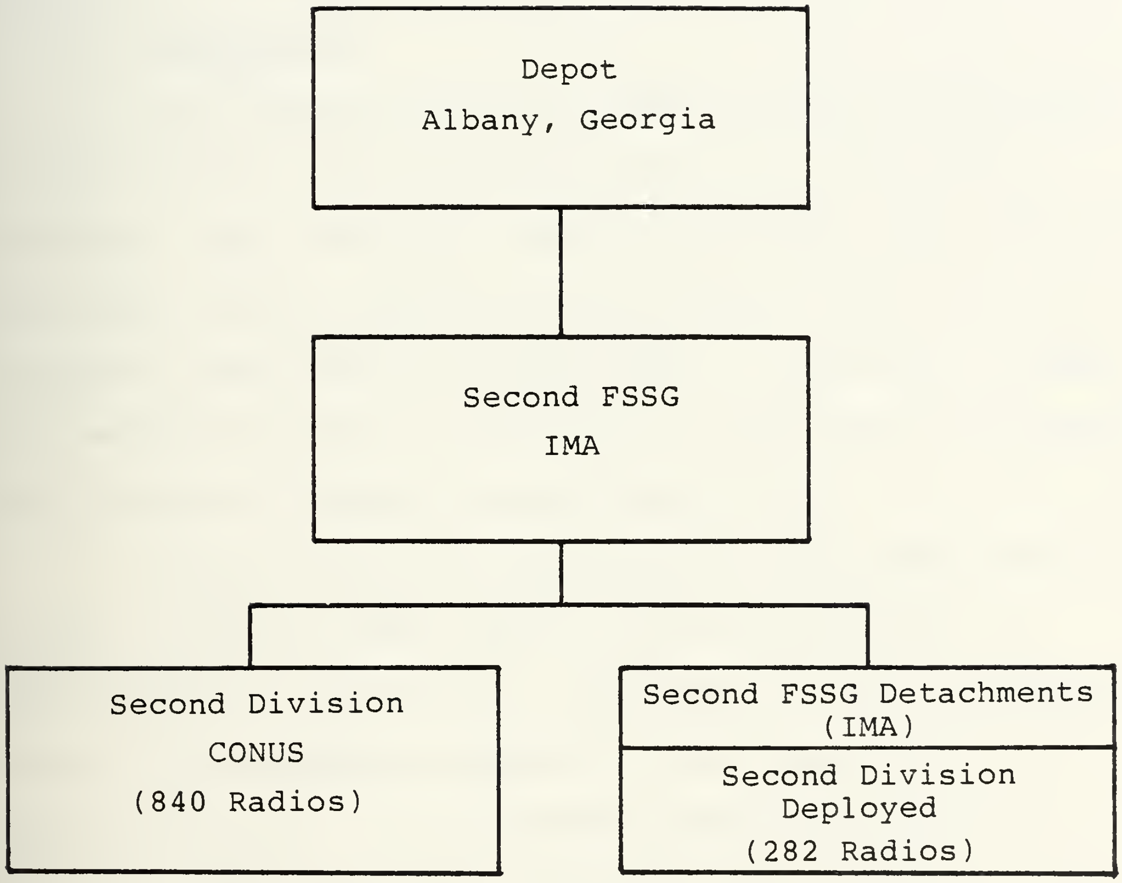
TABLE V-I

SECOND MARINE DIVISION AN/PRC-68 AUTHORIZATIONS [Ref. 14]

ORGANIZATION	TABLE OF EQUIPMENT
Headquarters Battalion	61
Infantry Battalions (9)	846 (94 each)
Combat Engineer Battalion	27
Artillery Regiment	124
Reconnaissance Battalion	64
TOTAL	1122

Figure V-3 shows the organizational structure as utilized in the linkup process. This structure, selected by the authors for analysis, is a modified version of the structure for the table of equipment with the stock/support points placed in the sequence. The structure illustrates Second Division separated into two forces. Forces remaining in the United States (CONUS) consist of the original table of equipment structure (Table V-I) minus three Infantry Battalions which are considered to be in some phase of deployment status. In this organization, only the Depot, Second FSSG, and FSSG detachments are authorized spares. The division is not authorized spares and is supported when deployed by FSSG detachments. Note, the FSSG is considered an Intermediate Maintenance Activity (IMA).

The linkup was accomplished utilizing the two stock/ support points in the Marine Corps for the AN/PRC-68.



NOTE: Second Division and Second FSSG are co-located activities.

Figure V-3. Organizational Structure

Table V-II shows the number of spares currently stocked at these locations. The high number of spares at the Depot level are stocked in support of Marine Corps, Navy, and Army units. The mountout quantities reflect the spares stocked within Second Force Service Support Group (FSSG) detachments for support of deployed division units.

1. Assumptions

Since the AN/PRC-68 is a new system and has been in the Fleet Marine Force less than one year, there is no historical lead time data. Depot procurement lead times and lead times between echelons of maintenance for acquiring spares are required by the ACIM model. The times provided were estimates based on the author's experience and information obtained on similar systems [Ref. 14].

Although it was not specified in the MCLOR analysis, for the purpose of the linkup it was assumed that the organizational level had the capability to test the AN/PRC-68, discard the consumable components, order and install the replacement parts. This assumption was verified by the AN/PRC-68 item manager at the Marine Corps Logistics Base, Albany, Georgia [Ref. 15].

The AN/PRC-68 is not combat essential. The using units can still perform their mission without this item. For the purpose of this thesis, however, we assume that the item is combat essential. For the purpose of the test problem, C 1 and C 2 categories of equipment readiness were run. The

TABLE V-II

INITIAL PROVISIONING OF SPARES [Ref. 14]

SECOND FSSG

ITEM	GARRISON SPARES	MOUNTOUT
AN/PRC-68	00	00
IF/AF	37	65
ANTENNA COUPLER	37	65
VCO	37	65
FILTER/IF	19	33
CONVERTER	37	65
MOD/MIXER	37	65
SYNTHESIZER	37	65
TRANSMITTER	37	65
FRAME/PANEL	102	00

NOTE: Garrison spares are primarily for support of CONUS units.

MARINE CORPS LOGISTICS BASE ALBANY (DEPOT)

ITEM	SPARES
IF/AF	461
ANTENNA COUPLER	427
VCO	461
FILTER/IF	237
CONVERTER	461
MOD/MIXER	461
SYNTHESIZER	461
TRANSMITTER	427
FRAME/PANEL	427

investment in spares was calculated to meet specified operational availabilities of 80% and 90%, respectively.

2. Primary ACIM Input Variables

a. Mean-Time-Between-Failure

The Marine Corps defines Mean-Time-Between-Failure (MTBF) as, "A basic measure of reliability for repairable items: The mean number of life units during which all parts of the item perform within their specified limits, during a particular measurement interval under stated conditions" [Ref. 16].

MTBF is a critical parameter of reliability. It represents a measure against which system performance capability can be related. Mission times must be known to assess the probability of accomplishing a given mission or predicting the probability of an item surviving (without failure) over a given period of time [Ref. 17]. MTBF is a given input in the MCLOR analysis and is the inverse of the failure rate (λ) at which failures occur in a specific time interval. This failure rate is computed by dividing the number of failures by the total operating hours. The MTBF for the system is then $\frac{1}{\lambda}$.

MTBF is not used as a direct input into the ACIM model. It is used indirectly in computing the Best Replacement Factor (BRF) (Section 5.B.3.c). The system MTBF for military equipment in an operational environment is often lower than the value obtained in formal reliability demonstration test, usually performed at the contractor's plant [Ref. 18].

Due to these changing MTBF values, it is important that this system characteristic be included in the sensitivity analysis as shown in the numerical example.

b. Mean-Time-To-Repair

The Mean-Time-To-Repair (MTTR) is defined in MIL-STD-721B "...as the total corrective maintenance time divided by the total number of total corrective maintenance actions during a given period of time" [Ref. 19].

The repair time includes the actions of the technician to diagnose (localize and isolate) the fault, remove and replace (or repair) the item, and verify the success of his actions. The actions of the technician are actual repair times at the authorized level and directly affect the Ao of the system (Equation 4-1). The MTTR in an operational environment may be higher than the value predicted or demonstrated by the manufacturer in a controlled environment [Ref. 20]. The MTTR for the test problem (4.62 hours or .19 day) was a given input in the MCLOR analysis which was used in the ACIM model (Figure V-2). The ACIM model requires MTTR in days for the system rather than for the individual LRI's. MTTR is a critical element in maintainability considerations for a system and is used in the numerical example for performing the sensitivity analysis.

3. Other Input Variables

a. SMR Codes

MCLOR data aids in the development of the Source, Maintenance and Recoverability Code (SMR Code). Appendix C1 provides the SMR code format and defines the various elements composing the SMR code. Based upon the optimal repair path output of the MCLOR model, Marine Corps maintenance policy decision-makers can use the MCLOR output as the SMR code or modify the output to derive SMR codes based on other factors such as experience or stockage policy. The Marine Corps maintenance and supply structure and a screening of technical files provide the basis for final SMR code assignment. The contractor may recommend SMR Codes based upon his maintenance engineers' test data, experience on similar items, or engineering judgment.

Once Marine Corps personnel receive the proposed SMR Code list from the contractor it is evaluated as to the applicability of the assignment of the SMR Codes. Marine Corps Logistics Base, Albany (MCLBA) makes the determination as to final assignment of SMR Codes.

The SMR Code indicates to maintenance and supply personnel the manner of acquiring items for the maintenance of equipment; the maintenance levels authorized to remove, replace, repair, assemble, manufacture, and dispose of support items; and the reclamation or disposition action required for items which are removed and replaced during maintenance [Ref. 2].

Table V-III provides the SMR Codes in the original linkup of MCLOR and ACIM for the test problem using the AN/PRC-68 data. These SMR codes reflect the optimal repair path as given by the MCLOR output.

TABLE V-III

MCLOR SMR CODES

ITEM	SMR CODE	MCLOR POLICY
IF/AF	PAOFF	Repair at 3rd echelon (IMA)
Antenna Coupler	PAOZZ	Discard
VCO	PAOZZ	Discard
Filter/IF	PAOZZ	Discard
Converter	PAOZZ	Discard
Mod/Mixer	PAOZZ	Discard
Synthesizer	PAOFF	Repair at 3rd echelon (IMA)
Transmitter	PAOZZ	Discard
Frame/Panel	PAOFF	Repair at 3rd echelon (IMA)

Sensitivity analysis of the elements of the SMR code provided in Section 5.C, demonstrates what happens when the repair path is changed and the effect this has upon operational availability and dollar costs.

b. Scrap Rate

A scrap rate is not given in the MCLOR analysis in direct terms but is assumed to be a washout rate which is computed from the Beyond Capability of Maintenance (BCM) rates obtained from MCLOR input data. The MCLOR System Users Manual defines washout as "The act of disposing a normally repairable item which cannot be repaired at the last authorized point in

the maintenance cycle. Washout may occur because the item is unserviceable, repair is not economically feasible, or the failure cannot be corrected" [Ref. 5]. The scrap rate derived from this definition applies to the three repairable LRI's (IF/AF, Synthesizer, Frame/Panel) of the AN/PRC-68. The process flow of these LRI's is organizational to third echelon. The MCLOR input data show repair not authorized at the organizational level and full repair capability at third echelon (IMA) with a BCM designated at 10%. This BCM rate represents the percentage of repairable items which cannot be repaired at the third echelon. since this echelon is the highest point of repair in the Marine Corps maintenance structure for the AN/PRC-68 LRI's, the BCM at that echelon is input to ACIM as a scrap rate.

The MCLOR analysis of the AN/PRC-68 showed that six LRI's of the radio were to be discarded on detection of a failure (Figure V-2). The MCLOR System Users Manual defines discard as, "A unique maintenance action where no attempt is made to repair a failed item; it is simply thrown away (discarded)" [Ref. 5]. Based on this definition, the six components identified by the analysis as discard items were assigned a scrap rate of 100% as an input to the ACIM model. The 10% scrap rate for the LRI's was used only in the linking process. The value will change depending upon the maintenance process flow being evaluated (Section V.4).

c. Best Replacement Factor

The Best Replacement Factor (BRF) is the projected annual replacement rate for one installed unit of a repair part. Only one BRF exists for each repair part, even if it is used in several different applications. In the case of initial provisioning, the BRF is determined by dividing the projected usage rate by the total installed population, yielding failures per population. The MCLOR analysis provides the total number of system operating hours per year, the MTBF of each item, and total number of systems to be deployed. Equation 5-1 was applied to the above MCLOR inputs in order to obtain the failures per population as required by the ACIM model. The failures per population were then divided by the total number of systems to yield the BRF which was rounded to three decimal places.

$$BRF_j = \frac{\frac{1}{MTBF_j} \times NEQP_j \times T_j}{TN_j} \qquad (5\text{-}1)$$

BRF_j = The BRF for type j equipment.

$MTBF_j$ = The Mean-Time-Between-Failures for type j equipment.

$NEQP_j$ = The number of items of type j in the system.

TN_j = The total number of type j equipments in the field.

T_j = The total mission time in hours.

$$\text{AN/PRC-68 BRF} = \frac{\frac{1}{10255} \times 1 \times 9{,}681{,}920}{4{,}960}$$

BRF = .190 (Rounded)

Reference 21 (Initial Spares Optimization Model) provides the equation for calculating the BRF assuming exponential distribution and statistical independence of failures. Equation 5-1 provides the BRF for the equipment and can be applied to each LRI by changing j to i (Equation 5-2).

$$BRF_i = \frac{\frac{1}{MTBF_i} \times NLR_i \times T_i}{TN_i} \qquad (5\text{-}2)$$

In the numerical example, each AN/PRC-68 has exactly one of each LRI and the operating time of all the LRI's is the same as the equipment so that:

$$BRF_j = \frac{\sum_{i=1}^{9} \left(\frac{1}{MTBF} \times NLRI_i\right) T_j}{TN_j} \qquad (5\text{-}3)$$

The BRF required by ACIM was computed based on a total population of 4960 radios. Although the test problem is limited to 1122 radios, the entire population had to be entered into the calculation due to the Marine Corps support of all Service's radios. The BRF input to ACIM for the initial linkup (Table V-IV) will change as the sensitivity analysis is performed on the MTBF in Section V.D.

TABLE V-IV

EQUIPMENT AND LRI BEST REPLACEMENT FACTOR

NOMENCLATURE	BRF
AN/PRC-68	.190
IF/AF	.027
Antenna/Coupler	.009
VCO	.010
Filter/IF	.003
Converter	.020
Mod/Mixer	.006
Synthesizer	.044
Transmitter	.003
Frame/Panel	.070

Due to rounding error, sum of LRI's equal .192 not .190.

C. ACIM TEST PROBLEM RESULTS

In this section, the output results of MCLOR are input to ACIM to calculate Ao and investment cost. Two computer runs were made utilizing 80% and 90% desired Ao, respectively. Table V-V shows the essential input data of the four sites.

Tables V-VI, V-VII, V-VIII, and V-IX, summarize the results in a side-by-side comparison of each of the four sites. Although Second Marine Division is not authorized spare radios or repair parts, ACIM consistently spared to the division (CONUS). Changes to ACIM input format were tried to eliminate this with no success. From the authors' understanding of ACIM, the model must spare at this level for the

TABLE V-V

MARINE CORPS ORGANIZATION DATA

SITE	NAME	ECH	S	R	TIME	CYC	SITES	EQUIP	Ao
1	ALBANY	5	X		180	0	1	1122	
2	FSSG	3	X	X	90	30	1	1122	
3	DIV CONUS	0			0	0	1	840	.80%/.90%
4	DIV DEPLOYED	0/3	X	X	30	7	1	282	.80%/.90%

SITE - Sequential numbering of the sites.

NAME - Site identification.

ECH - The echelon at which this site exist.

S - Supply source denoted by an "X".

R - Repair capability denoted by an "X".

TIME - Average length of time required, in days, for this site to obtain resupply from a higher supply source assuming supplies are immediately available at the source.

CYC - The average repair cycle in days for items repaired at this site.

SITE - The number of different locations represented by the site.

EQUIP- The number of equipments to be supported at the site (1122 total).

Ao - Desired Ao.

TABLE V-VI

DEPOT PROVISIONING

SITE 1

ITEM	IND	NOMENCLATURE	MSRT	QTY	UNIT PRICE
1	1	AN/PRC-68	0	0	
2	2	IF/AF	179.9	0	158.00
3	2	ANTENNA COUPLER	77.8	3	61.00
4	2	VCO	86.2	3	106.00
5	2	FILTER/IF	94.4	1	91.00
6	2	CONVERTER	68.3	7	118.00
7	2	MOD/MIXER	82.0	2	273.00
8	2	SYNTHESIZER	112.7	1	242.00
9	2	TRANSMITTER	94.4	1	179.00
10	2	FRAME/PANEL	134.5	1	397.00
	TOTAL	INVESTMENT =			$2782.00

ITEM - Sequential numbering of nomenclature items.

IND# - Indenture level. A number is entered (1-9) here according to the indenture level of the item in the parts breakdown of the equipment. A "1" is always entered in the first item record which represents the equipment.

NOMENCLATURE - Item description.

MSRT - (Mean-Supply-Response-Time) The average length of time, in days, required for a user of the equipment to obtain resupply from a higher supply source.

NOTE: At Site 1 (Depot), Ao has no affect on response times or stockage levels and there is no change in investment.

TABLE V-VII

SECOND FSSG PROVISIONING COMPARISONS

SITE 2

ITEM	IND	NOMENCLATURE	80% MSRT	80% QTY	90% MSRT	90% QTY	UNIT PRICE
1	1	AN/PRC-68	0	0	0	0	
2	2	IF/AF	7.3	5	3.8	6	158.00
3	2	ANTENNA COUPLER	25	5	13.2	6	61.00
4	2	VCO	21.7	6	21.7	6	106.00
5	2	FILTER/IF	17.5	3	17.5	3	91.00
6	2	CONVERTER	26.3	9	26.3	9	118.00
7	2	MOD/MIXER	20.7	4	20.7	4	273.00
8	2	SYNTHESIZER	8.8	6	5.4	7	242.00
9	2	TRANSMITTER	44.3	2	17.5	3	179.00
10	2	FRAME/PANEL	7.5	10	7.5	10	397.00
	TOTAL INVESTMENT		$9938		$10578		

At Site 2, an additional investment of $640 and a slight increase in stockage levels of items 2, 3, 9, and 10, enhanced the Ao for user Sites 3 and 4.

TABLE V-VIII

SECOND DIVISION CONUS PROVISIONING COMPARISONS

SITE 3

ITEM	IND	NOMENCLATURE	80% MSRT	80% QTY	90% MSRT	90% QTY	UNIT PRICE
1	1	AN/PRC-68	.34	0	.05	0	
2	2	IF/AF	.20	2	.03	2	158.00
3	2	ANTENNA COUPLER	.10	3	.009	3	61.00
4	2	VCO	.71	2	.08	3	106.00
5	2	FILTER/IF	1.02	1	.04	2	91.00
6	2	CONVERTER	.21	4	.04	5	118.00
7	2	MOD/MIXER	.71	1	.24	2	273.00
8	2	SYNTHESIZER	.15	3	.02	3	242.00
9	2	TRANSMITTER	.59	2	.04	2	179.00
10	2	FRAME/PANEL	.28	3	.06	4	397.00
		TOTAL INVESTMENT	$3822		$4807		

An additional investment of $985 and a slight increase of stockage levels for items 4, 5, 6, 7, and 10, was required.

NOTE: As stated in test problem results, the fact that ACIM spares to Second Marine Division (CONUS) is of little consequence. Taking into consideration the above short response times, the spares can be considered part of Site 2 (FSSG, IMA) due to its co-location with Second Marine Division.

TABLE V-IX

SECOND DIVISION DEPLOYED PROVISIONING COMPARISONS

SITE 4

			80%		90%		
ITEM	IND	NOMENCLATURE	MSRT	QTY	MSRT	QTY	UNIT PRICE
1	1	AN/PRC-68	1.45	0	.46	0	
2	2	IF/AF	.46	3	.32	3	158.00
3	2	ANTENNA COUPLER	1.10	2	.56	2	61.00
4	2	VCO	1.13	2	1.13	2	106.00
5	2	FILTER/IF	2.5	1	2.52	1	91.00
6	2	CONVERTER	.3	4	.15	4	118.00
7	2	MOD/MIXER	5.5	1	.41	2	273.00
8	2	SYNTHESIZER	1.7	3	.28	4	242.00
9	2	TRANSMITTER	6.0	1	2.52	1	179.00
10	2	FRAME/PANEL	1.4	4	.44	5	397.00
		TOTAL INVESTMENT	$4137		$5049		

This site experienced an investment increase of $972 and a slight increase in stockage levels for items 7, 8, and 10.

linkup of MCLOR and ACIM to provide any meaningful results. The results obtained from the desired Ao runs are considered reasonable when one considers the close proximity of the Second Division to its IMA. The spares allocated to the Second Division could augment the IMA spares with little or no change in Ao or investment cost. Therefore, the sparing to Second Division is considered of little consequence in the final results of Ao versus investment costs.

Table V-X shows the results obtained in the increase of Ao from 80% to 90%.

The final results are shown in Tables V-XI and V-XII. These tables list total LRI's spared to each site and the investment cost incurred.

1. Cost Comparison

Figure V-4 shows the cost versus Ao comparison for sites 3 and 4. The cost-effectiveness report from which the plots were taken to construct the curves is provided in Appendix C2. This report shows the selective sparing technique utilized by ACIM in order to achieve the highest Ao for sites 3 and 4 with each additional LRI's added to sites 1-4. Figure V-4 pertains only to the .90 desired Ao linkup run.

NOTE: Site 4 shows the least investment cost due to that site having its own organic repair/supply. In addition, site 4 is deployed and thus requires higher priorities resulting in shorter response times.

TABLE V-X

OPTIMIZATION MODE

	Site 3	Site 4	Site 3	Site 4
Ao Desired	.80	.80	.90	.90
Ao Achieved	.81139	.80567	.90438	.91205
Maximum Ao Obtainable	.92329	.97286	.92329	.97286
Total Investment	$20,679		$23,216	
Change in Investment	$2,537			

A 12.3% increase in investment gained a 10% increase in Ao.

TABLE V-XI

FINAL RESULTS OF 80% LINKUP

LRI	DEPOT 1 TOTAL SPARED	DEPOT 1 UNIT PRICE	FSSG 2 TOTAL SPARED	FSSG 2 UNIT PRICE	DIVISION CONUS 3 TOTAL SPARED	DIVISION CONUS 3 UNIT PRICE	DIVISION DEPLOYED 4 TOTAL SPARED	DIVISION DEPLOYED 4 UNIT PRICE
2	0	158	5	158	2	158	3	158
3	3	61	5	61	3	61	2	61
4	3	106	6	106	2	106	2	106
5	1	91	3	91	1	91	1	91
6	7	118	9	118	4	118	4	118
7	2	273	4	273	1	273	1	273
8	1	242	6	242	3	242	3	242
9	1	179	2	179	2	179	1	179
10	1	397	10	397	3	397	4	397
COST SUBTOTALS		$2782		$9938		$3822		$4137

TOTAL INVESTMENT $20,679

TABLE V-XII

FINAL RESULTS OF 90% LINKUP

LRI	DEPOT 1 TOTAL SPARED	DEPOT 1 UNIT PRICE	FSSG 2 TOTAL SPARED	FSSG 2 UNIT PRICE	DIVISION CONUS 3 TOTAL SPARED	DIVISION CONUS 3 UNIT PRICE	DIVISION DEPLOYED 4 TOTAL SPARED	DIVISION DEPLOYED 4 UNIT PRICE
2	0	158	6	158	2	158	3	158
3	3	61	6	61	3	61	2	61
4	3	106	6	106	3	106	2	106
5	1	91	3	91	2	91	1	91
6	7	118	9	118	5	118	4	118
7	2	273	4	273	2	273	2	273
8	1	242	7	242	3	242	4	242
9	1	179.	3	179	2	179	1	179
10	1	397	10	397	4	397	5	397
COST SUBTOTALS		$2782		$10578		$4807		$5049

TOTAL INVESTMENT $23,216

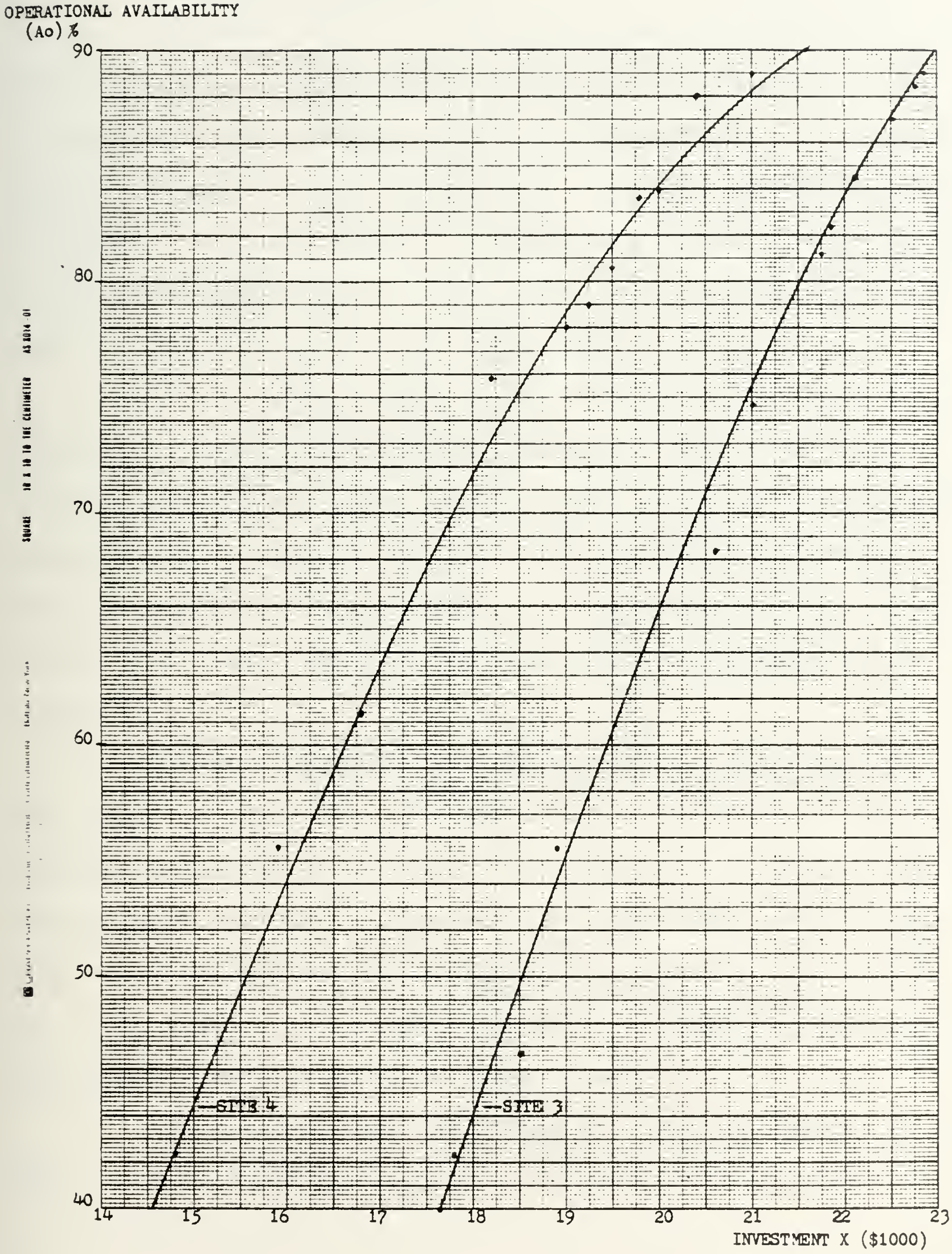


Figure V-4. Cost Comparison Curves

D. SENSITIVITY ANALYSIS

1. Repair Path Sensitivity

The repair path of the AN/PRC-68 as given by MCLOR is organizational to third echelon. The three repairable LRI's of the system are repaired only at third echelon (-3--) which reflects discard at that point if the item is beyond capability of repair. In researching the short background of the AN/PRC-68, it was discovered that the three LRI's are in fact being sent back to depot for full repair [Ref. 14].

In this section, the sensitivity of the ACIM model in relation to investment cost is explored as the repair path changes. The repair paths of the three LRI's of the AN/PRC-68 become third echelon to Depot (-3-D) to reflect the actual field procedures. The key input variables this change affects are the SMR codes, depot repair cycle time, and the scrap rates.

The SMR codes were changed to reflect Depot as the last point of repair for the three LRI's. The scrap rate was adjusted from 10% to 2% to reflect the enhanced repair capability of the depot. In the linkup process, the depot repair cycle time was originally given as zero since nothing went to the depot for repair. This was changed to 45 days to reflect the repair cycle of the LRI's at depot level.

This analysis was conducted utilizing a desired Ao of 90%. A summary of the results are shown in Table V-XIII.

TABLE V-XIII

SENSITIVITY COMPARISONS

	-3--		-3-D	
	Site 3	Site 4	Site 3	Site 4
Ao desired	.90	.90	.90	.90
Ao achieved	.90438	.91205	.90120	.91770
Maximum Ao obtainable	.92329	.97286	.92329	.97286
Total investment	$23,216		$20,346	
Change in investment	$2,870			

Table V-XIII indicates that a saving of 12.4% results as the repair path of the three LRI's shifts from full capability of repair at third echelon to full repair capability at Depot.

The MCLOR analysis of the AN/PRC-68 considered many cost variables, such as transportation of discarded items and storage space before arriving at an optimal repair path of third echelon (Chapter II). Field experience has dictated that keeping the LRI's in service as long as possible overrides the original MCLOR recommendation. It can be seen that this simple change has significant effect on cost while achieving the desired Ao.

2. Sensitivity to MTBF and MTTR

In this section the sensitivity of ACIM to changing system parameters (MTBF, MTTR) is explored. The tests consist of nine computer runs of the model with the Ao and the investment results compared to the original example results (Section V.C). The sequence of runs are:

Run 1 - Decrease the MTBF by 50%

Run 2 - Decrease the MTBF by 25%

Run 3 - Increase the MTBF by 25%

Run 4 - Increase the MTBF by 50%

Run 5 - Decrease the MTTR by 50% to .10 day or (2.31 hrs.)

Run 6 - Decrease the MTTR by 25% to .14 day or (3.47 hrs.)

Run 7 - Increase the MTTR by 25% to .24 day or (5.77 hrs.)

Run 8 - Increase the MTTR by 50% to .29 day or (6.93 hrs.)

Run 9 - Increase the MTTR by 100% to .38 day or (9.24 hrs.)

The change in MTBF has a direct effect on the number of item failures over the mission time and, therefore, increases or decreases the BRF's accordingly (Section V.B.3.c). Table V-XIV provides a summary of the MTBF changes and its effect on the BRFs.

Tables V-XV and V-XVI show the results obtained (Ao versus investment) from subjecting the MTBF and MTTR to sensitivity analysis. These tables provide a side-by-side comparison of the results obtained from the original MCLOR-ACIM linkup utilizing a 90% desired Ao.

NOTE: ACIM spares selectively in order to obtain the highest Ao for sites 3 and 4 with each additional LRI added to sites 1-4 (see Table IV-II). This can cause a slight decrease in Ao at a user site when, in theory the Ao should have increased. This effect can be seen in Table V-XV where site 4 actually experienced a decrease in Ao after the MTBF was increased. ACIM will stop the selective sparing at the first

TABLE V-XIV

SUMMARY OF MTBF CHANGES

	DECREASE 50%		DECREASE 25%		MCLOR DATA		INCREASE 25%		INCREASE 50%	
NOMENCLATURE	MTBF	BRF	MTBF	BRF	MTBF	BRF	MTBF	BRF	MTBF	BRF
AN/PRC-68	5128	.380	7691	.254	10255	.190	12819	.152	15383	.130
IF/AF	36539	.050	54808	.040	73078	.027	91347	.021	109617	.016
ANTENNA COUPLER	111850	.020	167775	.012	223700	.009	279625	.007	335550	.006
VCO	90716	.020	136074	.014	181432	.010	226790	.009	272148	.007
FILTER/IF	345758	.006	518636	.004	691515	.003	864394	.002	1037273	.002
CONVERTER	52739	.040	79108	.025	105477	.020	131846	.015	158216	.012
MOD/MIXER	157431	.012	236146	.008	314862	.006	393577	.005	472293	.004
SYNTHESIZER	22254	.088	33381	.058	44508	.044	55635	.040	66762	.030
TRANSMITTER	288901	.006	433351	.005	577801	.003	722251	.003	866702	.002
FRAME/PANEL	14068	.140	21101	.093	28135	.070	35169	.060	42203	.050

TABLE V-XV

MTBF SENSITIVITY

DESIRED Ao = .90

	DECREASE 50%		INCREASE 25%		MCLOR DATA		INCREASE 25%		INCREASE 50%	
SITES	3	4	3	4	3	4	3	4	3	4
Ao Achieved	.85700	.90156	.89961	.90780	.90438	.91205	.90231	.90000	.90531	.90701
MAX Obt Ao	.85751	.94716	.90003	.96405	.92329	.97286	.93767	.97817	.94621	.98127
Total Investment	$41,000.00		$31,685.00		$23,216.00		$19,812.00		$16,867.00	
Δ Investment	$17,784.00		$8,469.00				$3,404.00		$6,349.00	

TABLE V-XVI

MTTR SENSITIVITY

	DECREASES				MCLOR DATA		INCREASES					
MTTR	.10 Day		.14 Day		.19 Day		.24 Day		.29 Day		.38 Day	
SITES	3	4	3	4	3	4	3	4	3	4	3	4
Ao Achieved	.90174	.90359	.90252	.91819	.90438	.91205	.90199	.90598	.88718	.90000	.85725	.90108
MAX Obt Ao	.95810	.98553	.94231	.97986	.92329	.97286	.90502	.96596	.88746	.95916	.85751	.94716
Total Investment	$22,252.00		$22,767.00		$23,216.00		$24,510.00		$26,135.00		$26,287.00	
Δ Investment	$964.00		$449.00				$1,294.00		$2,919.00		$3,071.00	

fractional value obtained above the desired Ao or when the maximum obtainable Ao is reached.

Decreasing the MTBF reduces the Ao obtainable while increasing the investment cost. A decrease of 50% allows site 3 a maximum obtainable of only .85 and site 4 an achieved Ao of .90. This reduction in MTBF caused an investment increase of 77.0%. An increase of the MTBF resulted in an expected decrease of investment (27.3%) when the MTBF was increased by 50% and an improvement in the maximum Ao obtainable. Figure V-5 shows the relationship of investment to MTBF as obtained from the sensitivity analysis.

With each decrease in MTTR, a small savings of investment was encountered. The decreasing sensitivity run (.10 day or 2.31 hrs.) provided a total decrease in investment of 4%. This savings was a result of five less spares at site 3 and a decrease of one spare at site 4. Increasing the MTTR demonstrated increased investment cost while experiencing a decrease in the Ao achieved and maximum Ao obtainable. By doubling the MTTR (.38 day or 9.24 hrs.) an Ao of only .85 could be achieved at site 3. Although an additional 17 spares were stocked throughout the organizational structure, an Ao of 90% could not be obtained holding all other variables constant. Site 4 was capable of obtaining the desired Ao, but at an investment increase of 11.7%. Figure V-6 presents the relationship of investment to MTTR as demonstrated by the sensitivity analysis.

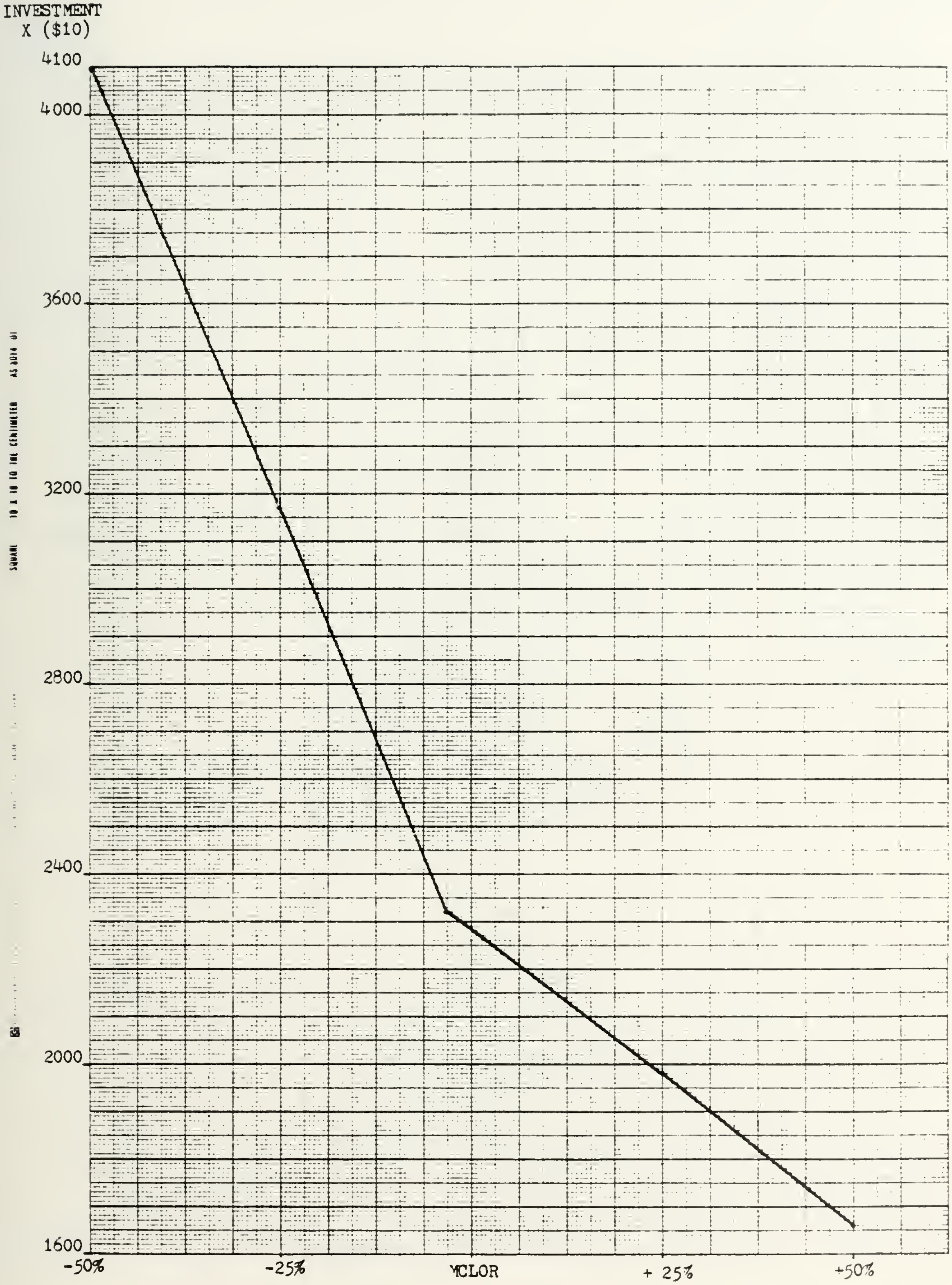


Figure V-5. MTBF Fluctuations

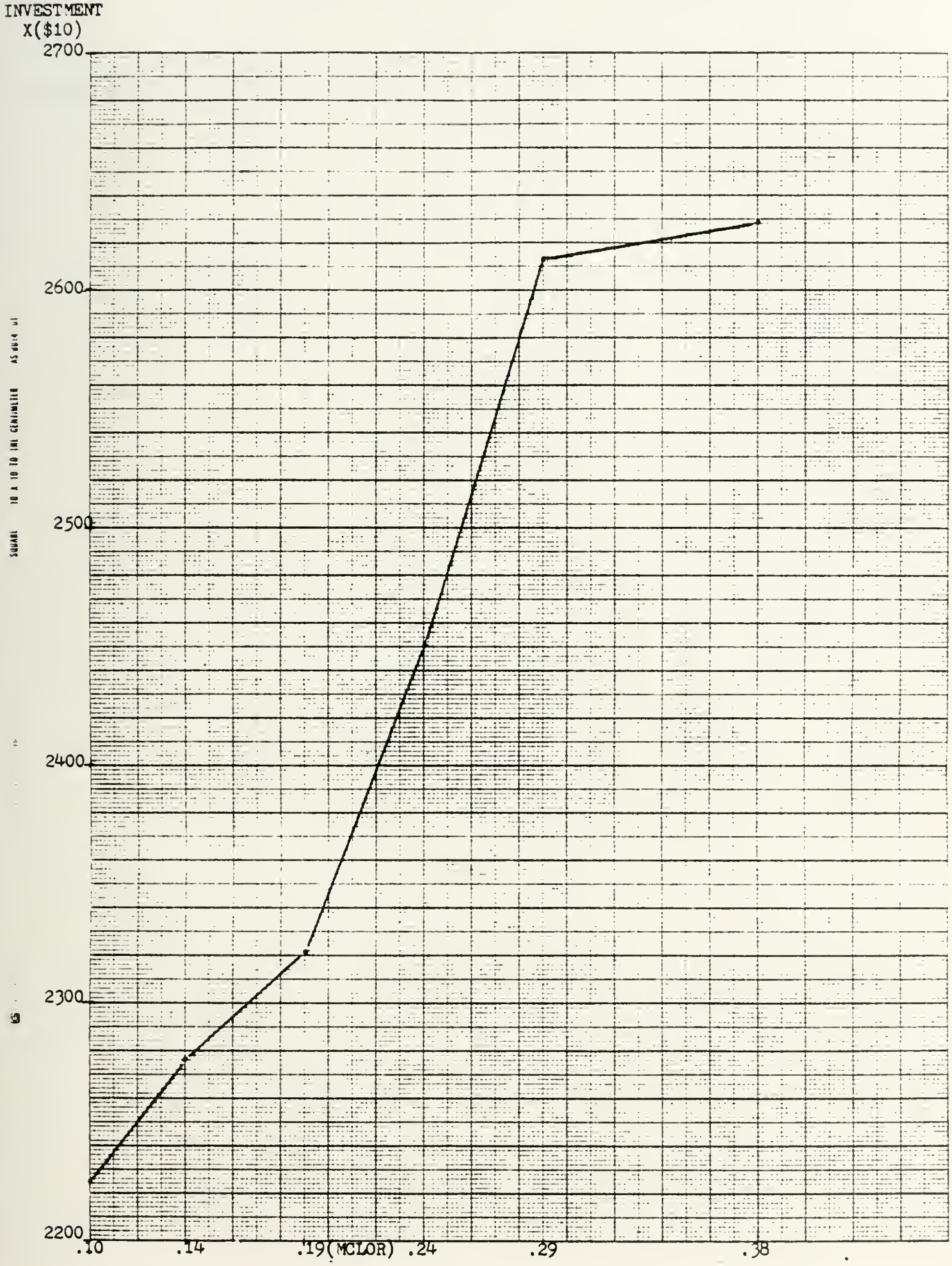


Figure V-6. MTTR Fluctuations

As shown in Tables V-XV and V-XVI, a drastic change in a critical variable which increases or decreases the reliability or maintainability of a system significantly impacts the maximum obtainable Ao.

VI. SUMMARY, CONCLUSIONS, RECOMMENDATIONS

A. SUMMARY

MCLOR is capable of meeting the decision-making needs of the Marine Corps on maintenance policies for new items of equipment. The model is user friendly; it has minimum data input requirements; its output reports are short and easily understood; and it provides a useful basis for determining level-of-repair requirements.

The ACIM model is being used in the Navy in a number of applications and appears to be useful for sparing to availability. ACIM was used in the numerical example of this thesis to establish the least-cost provisioning policy to achieve a specified system operational availability. The Marine Corps does not currently use a model to solve the provisioning/operational availability problem from the user's point of view. However, the Marine Corps is presently developing such a computer model, Initial Spares Optimization Model (ISOM).

The linking of MCLOR and ACIM was accomplished with minimum difficulty and produced results which can be effectively used by Marine Corps decision-makers for the initial allocation of spares. The success of the linkup relies on many factors which are interrelated. It can result in the achievement of providing support at the right time, in

the right quantity. A numerical example was provided to determine stock levels for all LRI's of the AN/PRC-68 system subject to given constraints.

ACIM produced a better mix of spares at a lower investment cost in achieving operational availabilities of 80% and 90% as compared to the initial provisioning. Since the optimal repair path of the AN/PRC-68 is organizational to third echelon, ACIM allocated fewer spares to depot which was designated as a source of supply with no repair capability. ACIM also provided a mix of spares to Second Marine Division. The Division was designated only a user and does not have supply or repair capability. ACIM proved to be sensitive to changing parameters and provided investment variations up to 77%. ACIM spares selectively to reach the desired Ao or maximum obtainable Ao.

B. CONCLUSIONS

Based on the results of the linkup (numerical example) and the sensitivity analysis performed, the following are concluded:

* A provisioning model is necessary to ensure the optimum allocation of spares at least cost.
* ACIM provides means of measuring the allocation of spares versus investment cost.
* ACIM can maximize material readiness while minimizing the risk of equipment non-availability to support the Marine Corps concept as a force in readiness.
* ACIM is a useful decision aid for budget formulation.
* The MCLOR and ACIM models can be used together to optimize the maintenance burden and to aid in the initial allocation of spares.

* The inputs required by ACIM can be derived from MCLOR input and output data.

* Important system parameters are Mean-Time-Between-Failure (MTBF), Mean-Time-To-Repair (MTTR), and Mean-Supply-Response-Time (MSRT).

* MTBF is more critical than MTTR, causing larger fluctuations in investment cost and allocation of spares.

* Care must be taken in the operational environment to ensure that the repair path (MCLOR output) is followed. A change in the repair path significantly affects investment cost and allocation of spares.

* The SMR codes (ACIM input) are assigned according to the repair path and are critical for the proper execution of ACIM. These codes provide the only basis for repair path information input to ACIM.

* The MTBF input to ACIM were specified values from MCLOR input. These values were determined prior to the AN/PRC-68 being placed into operation and will decrease in the field environment, thus causing a significant change in allocation of spares and investment cost.

C. RECOMMENDATIONS

We recommend that:

* The Marine Corps utilize a provisioning model which spares to availability to ensure the cost-effective allocation of spares.

* The Marine Corps ensure timely feedback from operational, maintenance, and supply personnel for comparison of MCLOR analysis with actual field procedures.

* When level-of-repair and provisioning analysis is being conducted, care should be taken to ensure the use of realistic input data, particularly with respect to the impact of the field environment to such parameters as MTBF and MTTR.

* The time parameters required by ACIM be placed in units of hours rather than days.

* The MCLOR model be used at the Marine Corps Logistics Base, Albany, Georgia.

APPENDIX A

SYSTEM STOCK

A. CONSUMABLE REPAIR PARTS

1. Provisioning requirements objective is equal to Procurement Cycle/Safety Level Quantity (PC/SL) plus Procurement Cycle Leadtime Quantity (PCLT).

PC/SL QTY. = A x B x C x (PC/SL)/360

PCLT QTY. = A x B x C x (PCLT)/360

Where:

A = Peacetime failure or replacement factor per end item per year.

B = Number of times the repair part is used in one end item.

C = Number of end items authorized using units by NAVMC 1017 (Table of Authorized Material, TAM), Table of Equipment (T/E), or supported by support units or employed by an entire Marine Amphibious Force.

2. An example:

PTB = 6 months (medium intensity managed)

TWAMP = 26 [Ref. 2]

A = 7.512 failure or replacement factor per end item per year

B = 2 (quantity per end item)

C = 26 end items supported (TWAMP)

PC/SL = 90 days

PCLT = 60 days

Therefore:

PC/SL QTY. = 7.512 x 2 x 26 x (90/360) = 97.66

PCLT QTY. = 7.512 x 2 x 26 x (60/360) = 65.10

and:

Provisioning Requirements Objective = 97.66+65.10=162.76=162

B. REPAIRABLES

1. Provisioning Requirements Objective is equal to Procurement Cycle/Safety Level Quantity (PC/SL) plus Procurement Leadtime Quantity (PCLT).

PC/SL QTY. = RR x (RCT/30) + RSR x (PC/SL/30)

PCLT QTY. = RSR x (PCLT/30)

Where:

RR = Repair Rate - The number of times per month that an unserviceable item replaced with a serviceable item is restored to a serviceable condition through maintenance action.

RSR = Resupply Rate - The quantity of unserviceable items replaced with serviceable items expected to be washed each month and to require replacement.

RCT = Repair Cycle Time - the time in days normally required for a repairable item to pass through the various stages from maintenance replacement until it is restored to a serviceable condition and returned to the float.

Note:

The sum of the depot repair rate (RR) and depot washout rates (RSR) equals the sum of the RSR's for the Marine Corps supported maintenance floats.

2. An example of a depot repairable item.

PCLT = 60 days

PC/SL = 90 days

Repair Cycle Time (RCT) for depot = 25 days

RR for depot = 20

RSR for depot = 10

Therefore:

PC/SL QTY. = 14 x (20/30) + 10 x (90/30) = 39.3

PCLT QTY. = 10 x (60/30) = 20

and:

Provisioning Requirements Objective = 39.3 + 20 = 59.3 = 59

3. An example of a repairable item anticipated to be disposed of below the depot level of maintenance.

PCLT = 60 days

PC/SL = 90 days

RCT for depot = 0

RR for depot = 0

RSR for depot = 15 (the sum of RSR's for all floats supported)

Therefore:

PC/SL QTY. = 0 x (0/30) + 15 x (90/30) = 45.0

PCLT QTY. = 15 x (60/30) = 30.0

and:

Provisioning Requirements Objective = 45.0 + 30.0 = 75.0

APPENDIX A1

INITIAL ALLOWANCE QUANTITY

A. INITIAL GARRISON OPERATING LEVEL (GOL)

The initial GOL of repair parts for using and support units will be based on predicated consumption within authorized day levels.

1. Consumables repair parts:

a. The total quantity stocked initially is equal to the quantity of repair parts required during the average cumulative order and shipping times of using and support units.

$$GOL\ QTY. = A \times B \times C \times OST/360$$

Where:

A = Peacetime failure or replacement factor per end item per year

B = Number of times the repair part is used in one end item

C = Number of end items authorized using units by NAVMC 1017 (Table of Authorized Material, TAM), Table of Equipment (T/E), or supported by support units or employed by an entire Marine Amphibious Force.

OST/360 = Cumulative average order and shipping time in days

All fractions are dropped.

B. EXAMPLE

The following example was extracted from MCO P4400.79C. The equation is applied to a repair part, such as a wheel bearing roller with the following results:

A = 0.5, authorized for removal and installation at organizational level maintenance.

B = 4

C = 112

OST = 120 days

Therefore:

$$GOL = .5 \times 4 \times 112 \times 120/360 = 74.7 = 74$$

1. <u>Repairable Items</u>

All initial repairable items are placed in a maintenance float. Assets are then segregated into operating and mount-out assets.

a. The stockage objective for each float is computed as follows:

$$GOL = (RR \times RCT/30) + (RSR \times DL/30)$$

Where:

GOL = Initial Garrison Operating Level for a maintenance float.

RR = Repair Rate - The number of times per month that an unserviceable item replaced with a serviceable item is restored to a serviceable condition through action.

RSR = Resupply Rate - The quantity of unserviceable items replaced with serviceable items expected to be washed out each month and to require replacement.

RCT = Repair Cycle Time - The time in days normally required for a repairable item to pass through the various unserviceable stages from maintenance replacement until it is restored to a serviceable condition and returned to the float.

DL = Day Level - The authorized initial secondary repairable item float levels expressed in days.

To arrive at the authorized levels, the Maintenance Replacement Rate (MRR) is also computed:

$$MRR = A \times B \times C/12 = RR + RSR$$

Where:

A = Peacetime failure or replacement factor per end item per year.

B = Number of times the repair part is used in one end item.

C = Number of end items authorized using units by NAVMC 1017 (Table of Authorized Material, TAM), Table of Equipment (T/E), or supported by support units or employed by an entire Marine Amphibious Force.

b. A sample computation is provided for MRR and GOL float.

Let:

A = 6.426 failure/replace factor per end item per year.

B = 1 used per end item.

C = 325 end items supported in Continental United States.

DL = 30 days as authorized by Appendix A to MCO p4400.79C.

RR = 24.74

RSR = 2.92

Support Period = 180 days

(1) $MRR = 6.426 \times 1 \times 325/12 = RR + RSR$

$MRR = 174.03 = RR + RSR$

(2) $GOL = (24.74 \times 22/30) + (2.92 \times 30/30)$

$GOL = 18.14 + 2.92 = 21.06 = 21$

c. Initial Mount Out (MO)

MO is held by using and support units. It is expressed as 60 days of combat consumption and is not based on OST.

(1) Consumable repair parts

(a) Mount out stocks will be computed against the following equation, for using and support organizations (3rd and 4th echelon). A 60 day level is authorized for those items for which predicted consumption is one or more during the first 60 days of combat for active forces (inactive forces will be authorized a 30 day level).

$$MO = A \times B \times C \times 60/360$$

(b) If the predicated combat consumption of a critical support item fails to compute one in the total of prepositioned war reserves plus mount out, then MO is recomputed as follows:

$$MO = A \times B \times C \times 360/360$$

No more than one will be stocked as a result of this computation; it will be stocked as an NSO item.

(c) Critical repair parts for low density equipment will also be authorized for stockage at the 4th echelon support units mount out.

Using the values provided in A.1.b. herein a computation is made.

$$MO = 0.5 \times 4 \times 112 \times (60/360) = 37.33 = 37$$

(2) Repairable

(a) The stockage objective of each mount out float is:

$$MO = (RR \times RCT/30) + (RSR \times 60/30)$$

(b) A sample computation using the variables values provided in A.2.b. follows:

$$MO = (24.74 \times 22/30) + (2.92 \times 60/30) = 18.14 + 5.84 = 23.98 = 24$$

APPENDIX A2

PREPOSITIONED WAR RESERVES

A. CONSUMABLES

1. PWR is a segment of the total Prepositioned War Reserve Material Stocks (PWRMS) issued to the active forces. For an initial PWRMS a computation will be made for each Marine Amphibious Force (MAF) and the 4th Marine Division/Wing Team. The equation follows:

PWRMS = A x B x C x Support Period (days)/360 days

Where:

A = Peacetime failure or replacement factor per end item per year.

B = Number of times the repair part is used in one end item.

C = Number of end items authorized using units by NAVMC 1017 (Table of Authorized Material, TAM), Table of Equipment (T/E), or supported units or employed by an entire Marine Amphibious Force.

Support Period = 180 days for 2nd and 3rd MAF, 150 days for 1st MAF and 90 days for 4th DWT.

The initial resupply level or PWR level for each MAF would thus be constructed as:

Resupply = PWRMS - MO

Where:

PWRMS = value computed above.

MO = value computed in Appendix A1 (B.1.c(1)(c)).

2. An example of the computation follows:

A = 0.5

B = 4

C = 112

Support Period = 180

Therefore:

PWRMS = 0.5 x 4 x 112 x (180/360) = 112

and

MO = 0.5 x 4 x 112 x (60/360) = 37

Thus

Resupply = 112 - 37 = 75

B. REPAIRABLES

1. Each MAF resupply is based on an established Resupply Rate (RSR).

Resupply = Supported Period (days) - 60 x RSR/30 days

Where:

Support Period (days) = same as A.1 above.

RSR = Resupply Rate - the quantity of unserviceable items replaced with serviceable items expected to be washed out each month and to require replacement.

2. A sample computation is provided. Let:

Support Period = 180 days

RSR = 2.92

Therefore:

Resupply = (180 - 60 x 2.92/30) = 11.68 = 12

APPENDIX B

MCLOR OUTPUT [Ref. 5]

U.S. MARINE CORPS LEVEL OF REPAIR ANALYSIS
TEST (FICTIONAL DATA) 6 ITEMS

SNAPSHOT

SYSTEM SUMMARY

INVENTORY	26141968.		
INVENTORY STORAGE SPACE	1674343.		
TRANSPORTATION	5737862.		
MATERIAL	75648784.		
LABOR	19451568.		
TRAINING	27605.		
ITEM ENTRY & RETENTION	77974.		
TOTAL VARIABLE COSTS		128760080.	
REPAIR WORK SPACE	9216821.		
SUPPORT EQUIPMENT	85300.		
SUPPORT EQUIP SPACE ...	90840928.		
SUPPORT EQUIP SUPPORT .	18802.		
PSE DOCUMENTATION	6500.		
TOTAL FIXED COSTS		100168336.	
TOTAL COSTS			228928416.

SYSTEM REPAIR PATH 03-D

U.S. MARINE CORPS LEVEL OF REPAIR ANALYSIS
TEST (FICTIONAL DATA) 6 ITEMS

LSA CONTROL NUMBER	ITEM IDENTIFIER	REPR PATH	VAR COST	FIXED COST	TOTAL COST
001.000.000	UNIT NO. 1	03-D	47405920	47217744	94623664
001.001.000	ASSEMBLY NO. 1	03-D	4814948	6030783	10845731
001.001.001	LRI NO. 1	-3-D	587128	1924239	2511367
001.001.002	LRI NO. 2	DSCD	217417	0	217417
001.002.000	ASSEMBLY NO. 2	03-D	4814948	6030783	10845731
002.000.000	UNIT NO. 2	---D	70919744	38964768	109884512
	TOTALS		128760080	100168336	228928416

U.S. MARINE CORPS LEVEL OF REPAIR ANALYSIS
TEST (FICTIONAL DATA) 6 ITEMS

LSA CONTROL NUMBER	INV	INV STOR SPACE	TRANS	MATL	LABOR	TRNG	ITEM ENTRY	REPR WORK SPACE	SUPPT EQUIP	SUPPT EQUIP SPACE	SUPPT EQUIP SUPPT	PSE DOCUM
001.000.000	806620	57011	552615	35848240	10119332	6840	15289	4792614	39777	42374176	8118	3080
001.001.000	133691	9192	54257	3575135	1020545	6840	15289	528178	4168	5497075	1056	307
001.001.001	44865	3042	50188	354607	114327	4811	15289	103590	614	1819656	351	30
001.001.002	201037	12088	2763	0	0	0	1529	0	0	0	0	0
001.002.000	133691	9192	54257	3575135	1020545	6840	15289	528178	4168	5497075	1056	307
002.000.000	24822064	1583817	5023783	32295712	7176832	2275	15289	3264261	36574	35652960	8221	2775
TOTALS	26141968	1674343	5737862	75648784	19451568	27605	77974	9216821	85300	90840928	18802	6500

APPENDIX B1

MCLOR ROUTINES [Ref. 5]

BLKDATA
- o Initializes Model Variables

MAIN
- o Initiates Data Input
- o Initiates Data Echo
- o Iterates Through All Items
- o Selects Cases for Evaluation
- o Initiates Cost Calculations
- o Selects Minimum Cost Cases
- o Initiates Reallocation of Costs
- o Performs Sensitivity Analysis
- o Initiates Output Reports

INPUT2
- o Performs All Data Input
- o Performs Error Checking
- o Calculates Various Initial Values

ECHO1
- o Prints All System Variables

ECHO2
- o Iterates Through All Items
- o Prints All Item Variables

CALCV
- o Calculates Variable Costs For Repair Cases
  - oo Spares Costs
  - oo Inventory Storage Space Costs
  - oo Material Costs
  - oo Transportation Costs
  - oo Training Costs
  - oo Labor Costs
  - oo Item Entry & Retention Costs

CALCW
- o Calculates Variable Costs For Discard Case
  - oo Spares Costs
  - oo Inventory Storage Space Costs
  - oo Transportation Costs
  - oo Item Entry & Retention Costs

CALCSE
o Calculates Fixed Costs
  oo Support Equipment Capital Costs
  oo Support Equipment Space Costs
  oo Repair Work Space Costs
  oo Documentation Costs
  oo Support of Support Equipment Costs
o Allocates Fixed Cost to Each Item

CALCFC
o Calculates System Fixed Costs (Without Allocation)

VOPT
o Selects Valid Cases
o Calculates Variable Costs
o Sums Costs by item and Fixed Cost Cases

CALCF
o Calculates Total Fixed Costs by Case
  oo Repair Work Space
  oo Each Type of Common Support Equipment
  oo Each Type of Peculiar Support Equipment

OUTPUT
o Prints
  oo System Cost totals
  oo Item Cost Totals
  oo Item Cost Breakdown
  oo SE Utilization

PAGER1
o Prints Out Page Headers and Numbers
o Counts Output Lines for Pagination

AVALUE
o Returns Alphabetic Character From Input Stream

RVALUE
o Returns Integer Number From Input Stream

ERROR
o Prints Error Message and Last Card Read

APPENDIX C

AN/PRC-68 PARAMETERS [Ref. 13]

A. Marine Corps Level-of-Repair (MCLOR) input and output data utilized to exercise the Availability-Centered Inventory Model (ACIM). Table C-I shows the system and LRI's Mean-Time-Between-Failures (MTBFs), item cost, failures per year and items per system.

1. Input Data

- o Number of systems - 4960
- o Number of operating hours per system per year - 1952
- o Number of years in the life cycle - 10
- o Depot repair cycle time - 45 days (Sensitivity Analysis)
- o Total item operating hours per year - 9,681,920
- o system Mean-Time-To-Repair (MTTR) - 4.62 hours (.19 day)

2. Output Data

The output data utilized in the linkup is shown in Table C-II.

TABLE C-I

INPUT DATA

ITEM	MTBF (HRS)	ITEM COST	FAILURES PER YEAR	ITEMS PER SYSTEM
AN/PRC-68	10255	1625	944.12	1
IF/AF	73078	158	132.49	1
ANTENNA COUPLER	223700	61	43.28	1
VCO	181432	106	53.36	1
FILTER/IF	691515	91	14.00	1
CONVERTER	105477	118	91.79	1
MOD/MIXER	314862	273	30.75	1
SYNTHESIZER	44508	242	217.53	1
TRANSMITTER	577801	179	16.76	1
FRAME/PANEL	28135	397	344.12	1

NOTE: The MTBFs are given values based on system specifications and have since decreased by approximately 10%.

TABLE C-II

OUTPUT DATA

ITEM	OPTIMAL REPAIR PATH
AN/PRC-68	ORGANIZATIONAL TO 3RD ECHELON (IMA)
IF/AF	3RD ECHELON (IMA)
ANTENNA COUPLER	DISCARD
VCO	DISCARD
FILTER/IF	DISCARD
CONVERTER	DISCARD
MOD/MIXER	DISCARD
SYNTHESIZER	3RD ECHELON (IMA)
TRANSMITTER	DISCARD
FRAME/PANEL	3RD ECHELON (IMA)

APPENDIX C1

SMR CODE FORMAT

Table C-III shows the SMR code format and Table C-IV the SMR code elements. By combining the elements, the SMR code is formed and maintenance and supply instructions are communicated to the logistics support and user level. The codes are made available to their intended users by means of technical publications, such as allowance lists, illustrated parts breakdowns, maintenance manuals and supply documents.

A part coded as PAOZZ indicates that it is to be procured and stocked by the Marine Corps, that, units having first and second echelon maintenance capability (organizational level) are authorized to remove, replace and use the item, and that this item is not repairable and is discarded at organizational level.

TABLE C-III

SMR CODE FORMAT [Ref. 2]

SOURCE CODES	MAINTENANCE CODES	RECOVERABILITY CODES	
(1) (2)	(3)	(4)	(5)
Means of acquiring support items.	Lowest maintenance level authorized to remove, replace and use the item.	Indicates whether the item is to be repaired and identifies lowest level of maintenance with the capability to perform complete repair: i.e., all authorized maintenance functions.	Indicates disposition of item.

TABLE C-IV

SMR CODE ELEMENTS [Ref. 2]

1. Source codes (first two letters)

   PA - Item procured and stocked for anticipated/known usage.

   PB - Item procured and stocked for insurance purposes.

   PC - A PA item that has a limited shelf life.

   PD - Support item, excluding support equipment, procured for initial issue or outfitting.

   PE - Support equipment procured and stocked for initial issue or outfitting to specified maintenance repair activities.

   PF - Support equipment, not stocked, but certainly procured upon demand.

   PG - Item procured and stocked for sustained support of the life of the equipment.

2. Maintenance Codes (third letter)

   O - First and Second Echelon.

   F - Third Echelon.

   H - Fourth Echelon.

   D - Depot (Fifth) Echelon.

3. Recoverability Codes (fourth & fifth letter)

   O - First and Second Echelon Dispose.

   A - Item requires special handling.

   D - Return to depot.

   F - Third Echelon Dispose.

   H - Fourth Echelon Dispose.

   L - Repair, condemnation is not authorized below the depot/special repair activity level.

   Z - Non-repairable, dispose of by activity in column three of SMR.

APPENDIX C2

COST EFFECTIVENESS REPORT

ITEM	COST	SITE	LEVEL	USER	ASUBO	CUMCOST
3	61	4	1	4	0.047814	61
3	61	4	2	4	0.049252	122
4	106	4	1	4	0.051515	228
6	118	4	1	4	0.054254	346
6	118	4	2	4	0.057155	464
6	118	4	3	4	0.060010	582
3	61	2	1	3	0.020391	643
3	61	2	2	3	0.020702	704
3	61	1	1	3	0.021019	765
3	61	3	1	3	0.021450	826
3	61	2	3	3	0.021764	887
4	106	4	2	4	0.064350	993
3	61	1	2	3	0.022051	1054
4	106	2	1	3	0.022417	1160
4	106	2	2	3	0.022795	1266
4	106	1	1	3	0.023184	1372
4	106	2	3	3	0.023579	1478
6	118	4	4	4	0.070033	1596
3	61	2	4	3	0.023849	1657
5	91	3	1	3	0.024334	1748
5	91	2	1	3	0.024651	1839
6	118	2	1	3	0.025109	1957
6	118	2	2	3	0.025585	2075
6	118	2	3	3	0.026079	2193
2	158	4	1	4	0.078498	2351
6	118	1	1	3	0.026593	2469
5	91	2	2	3	0.026815	2560
6	118	2	4	3	0.027359	2678
4	106	3	1	3	0.028090	2784
6	118	1	2	3	0.028687	2902
6	118	2	5	3	0.029309	3020
8	242	4	1	4	0.089313	3262
4	106	1	2	3	0.029884	3368
6	118	3	1	3	0.030794	3486
6	118	3	2	3	0.031756	3604
6	118	3	3	3	0.032759	3722
2	158	4	2	4	0.094338	3880
6	118	1	3	3	0.033543	3998
6	118	3	4	3	0.034557	4116
8	242	4	2	4	0.102498	4358
4	106	2	4	3	0.035260	4464
6	118	2	6	3	0.036058	4582
3	61	3	2	3	0.036579	4643

ITEM	COST	SITE	LEVEL	USER	ASUBO	CUMCOST
2	158	2	1	3	0.037586	4801
2	158	2	2	3	0.038594	4959
9	179	4	1	4	0.111958	5138
6	118	1	4	3	0.039458	5256
2	158	3	1	3	0.040816	5414
4	106	3	2	3	0.041764	5520
7	273	4	1	4	0.122823	5793
5	91	1	1	3	0.041988	5884
9	179	2	1	3	0.043219	6063
8	242	2	1	3	0.044647	6305
8	242	2	2	3	0.046166	6547
6	118	2	7	3	0.047217	6665
8	242	2	3	3	0.048887	6907
8	242	2	4	3	0.050596	7149
2	158	2	3	3	0.051872	7307
10	397	4	1	4	0.161578	7704
7	273	2	1	3	0.053930	7977
7	273	2	2	3	0.056079	8250
8	242	2	5	3	0.058139	8492
9	179	2	2	3	0.059969	8671
6	118	1	5	3	0.061363	8789
7	273	1	1	3	0.063991	9062
4	106	1	3	3	0.065105	9168
8	242	3	1	3	0.068885	9410
3	61	1	3	3	0.069604	9471
10	397	4	2	4	0.219224	9868
7	273	2	3	3	0.072460	10141
8	242	1	1	3	0.074839	10383
2	158	2	4	3	0.076638	10541
10	397	2	1	3	0.081251	10938
10	397	2	2	3	0.086455	11335
10	397	2	3	3	0.092367	11732
10	397	2	4	3	0.099130	12129
10	397	2	5	3	0.106903	12526
10	397	2	6	3	0.115841	12923
10	397	1	1	3	0.126063	13320
10	397	2	7	3	0.137706	13717
10	397	2	8	3	0.150480	14114
9	179	3	1	3	0.161988	14293
6	118	1	6	3	0.169174	14411
5	91	2	3	3	0.170183	14502
7	273	3	1	3	0.190698	14775
5	91	4	1	4	0.424359	14866
10	397	2	9	3	0.212779	15263
8	242	2	6	3	0.227621	15505
10	397	4	3	4	0.554560	15902
10	397	3	1	3	0.278682	16299
4	106	2	5	3	0.289691	16405
6	118	2	8	3	0.303467	16523
8	242	4	3	4	0.613842	16765

ITEM	COST	SITE	LEVEL	USER	ASUBO	CUMCOST
2	158	2	5	3	0.318978	16923
7	273	1	2	3	0.345080	17196
3	61	2	5	3	0.342085	17257
10	397	2	10	3	0.401549	17654
9	179	1	1	3	0.423210	17833
10	397	4	4	4	0.755737	18230
8	242	3	2	3	0.467306	18472
10	397	3	2	3	0.555368	18869
2	158	4	3	4	0.781771	19027
6	118	2	9	4	0.784874	19145
4	106	2	6	4	0.790346	19251
7	273	2	4	4	0.805676	19524
8	242	4	4	4	0.835736	19766
2	158	2	6	4	0.837762	19924
3	61	2	6	4	0.840394	19985
10	397	4	5	4	0.881016	20382
9	179	2	3	3	0.684281	20561
10	397	3	3	3	0.746919	20958
6	118	1	7	4	0.889366	21076
8	242	2	7	4	0.892931	21318
7	273	4	2	4	0.912053	21591

0.9000 AVAILABILITY TARGET REACHED AT SITE 4

2	158	3	2	3	0.812304	21749
4	106	3	3	3	0.821819	21855
7	273	3	2	3	0.845261	22128
10	397	3	4	3	0.870836	22525
8	242	3	3	3	0.885058	22767
5	91	3	2	3	0.890332	22858
6	118	3	5	3	0.896695	22976
3	61	3	3	3	0.898954	23037
9	179	3	2	3	0.904395	23216

0.9000 AVAILABILITY TARGET REACHED AT SITE 3

TARGET/MAXIMUM AVAILABILITY REACHED AT ALL SITES.

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Thesis
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