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DEVELOPMENT OF THE SEABORNE MOBILE LOGISTIC SYSTEM (SMLS) MAINTENANCE OPTIMIZATION MODEL, VERSION I

by

Michael Gray

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COMPUTATION AND MATHEMATICS DEPARTMENT
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DEVELOPMENT OF THE SEABORNE MOBILE LOGISTIC SYSTEM (SMLS) MAINTENANCE OPTIMIZATION MODEL, VERSION I 4116

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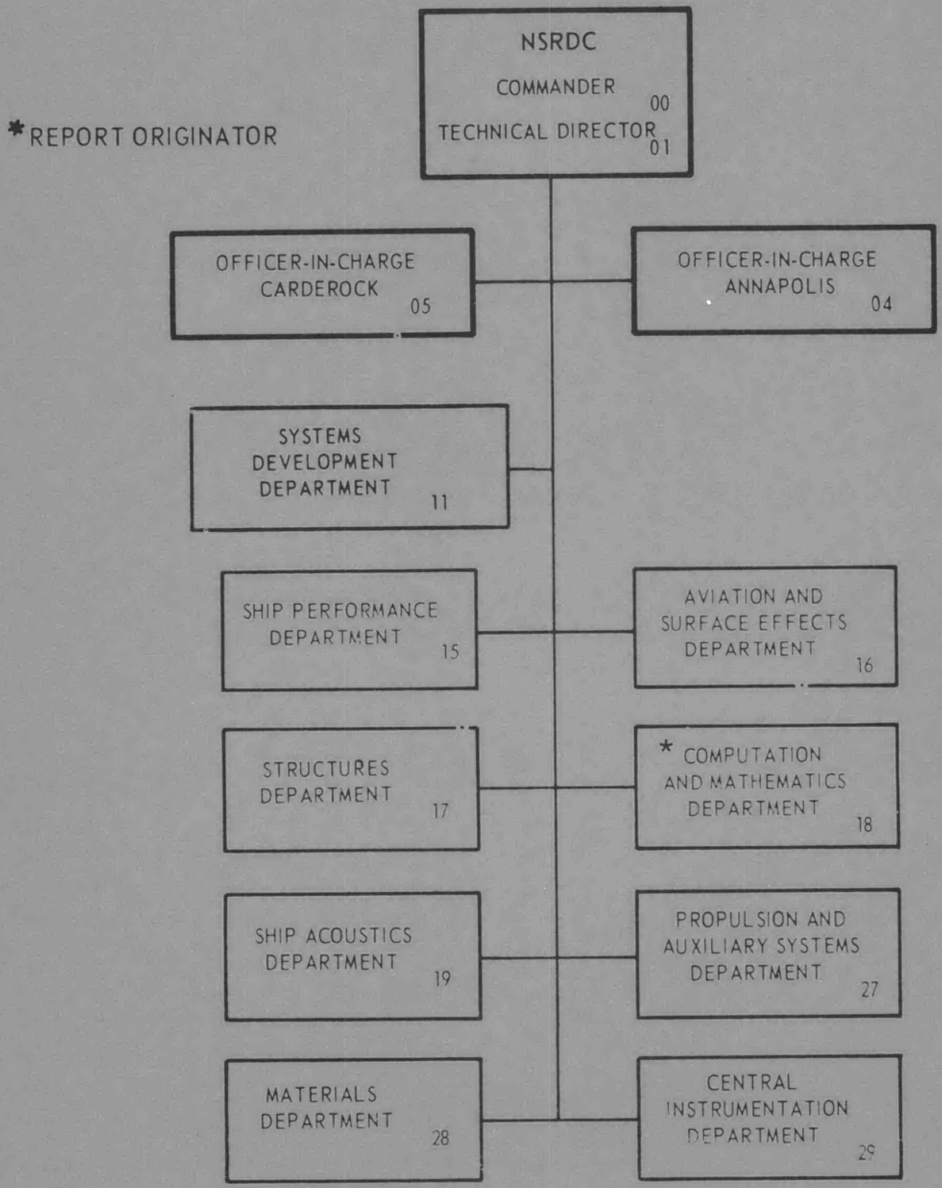

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20 ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Seaborne Mobile Logistic System (SMLS) defines operational procedures and allocation of resources for logistically supporting a Marine Corps Landing Force ashore from a seabase afloat. A maintenance computer model to demonstrate the feasibility of, and to determine the requirements for, performing maintenance under SMLS is developed. (A user's guide to the model has been documented separately.) This report describes the technical and operational aspects of the simulation.

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20. Procedures for computing measures of effectiveness (MOE's), availability of the landing-force end items, and utilization statistics of the maintenance system are presented. Monte Carlo techniques, queuing procedures, and generation of failure and repair times are discussed as they are used in the model. Results of running various SMLS configurations, with either contact teams or selective unit maintenance, are compared to the baseline configuration: the 34th Marine Amphibious Unit (MAU). The results indicate that SMLS maintenance is both feasible and cost effective when compared to the conventional system. Centralization of 2nd-echelon repair and the ability to perform 4th-echelon repair in the seabase are key factors.

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SECTION 1
INTRODUCTION

Changing world situations require new initiatives in defense strategy, particularly in amphibious operations, where there is an ever-growing need to structure forces differently from the conventional theater warfare style. In the conventional style, an Amphibious Task Force (ATF) transports an entire Marine Corps Landing Force to the Amphibious Objective Area (AOA) and then disembarks the force ashore with all its logistic support. After disembarking men and equipment, the ATF leaves the AOA. In a new approach to amphibious operations, certain elements of the Landing Force do not go ashore but operate from seabased ships which are part of the ATF. Operations ashore are logistically supported through the seabased elements of the Landing Force. This seabasing concept minimizes the logistics buildup ashore but permits the logistics capability to be moved ashore if the situation dictates.

Support of forces incorporating the seabasing concept involves highly complex transportation, communications and coordination requirements. However, maintenance, supply, and medical operations are performed more efficiently and at the same time, require fewer resources than conventional procedures. The application of such a seabasing concept requires that new procedures and operations be developed. Thus, the Seaborne Mobile Logistic System (SMLS), which specifies procedures and operations for logistic support of a Landing Force through a seabase, is under development.

The performance of maintenance to support amphibious operations through SMLS requires alterations to the conventional procedures and operations, and involves, in addition, relocation of resources and personnel. It is desirable to perform these alterations and relocations in an optimal manner. At the same time, it is necessary to determine requirements for performing maintenance under SMLS, and to compare SMLS procedures with conventional procedures.

For this work, two computer simulation models were developed as an efficient way of examining major tradeoffs, parameters, and requirements of the SMLS maintenance system. Through the models, the cost effectiveness of various SMLS maintenance configurations was evaluated by comparison with the type of maintenance configuration used in conventional amphibious oper- operation.

The first model, known as the SMLS Simulation Model[1], considers maintenance, supply, medical, transportation, communications, and coordination subsystems interacting with one another in the total Seaborne Mobile Logistic System. The scope of SMLS necessitated a large complex model to serve as an effective tool for examining the overall SMLS operations. However, to determine the characteristics and requirements of the maintenance subsystem to the appropriate degree of detail, the following factors not presently in the SMLS simulation model required examination:

- specific replacement end items (end items are operational equipment used by the Landing Force)
- maintenance personnel
- maintenance equipment
- locations and degree of maintenance

Size constraints did not permit these factors to be implemented in the present systems model. Therefore, the Maintenance Optimization Model was developed to

- examine the significance of the additional factors mentioned
- measure the cost effectiveness of the detailed maintenance system, and
- determine maintenance space requirements.

Model input and output definition, concepts such as event generation and queuing theory description, and a complete program listing are included in a report by Marcus.[2]

Subsequent work refining the results given in this report will be described in forthcoming documents.

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[1] Hubai, P., Humfeld, G.R., and Fuller, J. J., Computer Simulation Model for Seaborne Mobile Logistic System (SMLS) at the Amphibious Task Unit/ Marine Amphibious Unit (ATU/MAU) Level, Part 1 Model Description, NSRDC Report 4114, to be published.

[2] Marcus, C. Y., and Gray, M., Seaborne Mobile Logistic System (SMLS), Maintenance Optimization Model User's Manual, NSRDC Report 4115, August 1973

SECTION 2

MAINTENANCE CONCEPTS

The elements of the Landing Force which perform maintenance at the seabase consist mainly of USMC personnel. The maintenance procedures used in SMLS are thus based on those presently used by the Marine Corps. For a clear understanding of maintenance performed under SMLS, important concepts of Marine Corps maintenance are defined.

2.1 PREVENTIVE AND CORRECTIVE MAINTENANCE

"Maintenance is the action taken to retain material in a serviceable condition, or to restore it to serviceability."[3] When an end item or part of an end item (material) becomes inoperative or its operation is sufficiently degraded, corrective maintenance is required. Corrective maintenance includes those procedures required to restore failed end items to normal operation; i.e., to serviceability. Preventive maintenance comprises those procedures performed on end items on some periodic basis rather than only when a failure occurs. The purpose of preventive maintenance is to retain items in serviceable condition by reducing operational failures and thus corrective maintenance requirements. In the maintenance model described here, only corrective maintenance was specifically considered. The performance of preventive maintenance when required is implied.

2.2 ECHELONS OF MAINTENANCE

"To define clearly the assignment of maintenance missions and responsibilities in keeping with policy established by the Department of Defense, all maintenance operations except aviation maintenance have been grouped into three broad categories: organizational, field, and depot maintenance. For the purpose of providing further flexibility and accuracy in defining maintenance operations, the three broad categories of maintenance have been subdivided into five echelons of maintenance, which are numbered consecutively from 1 through 5."[3]

These echelons are defined in Table 1. This analysis considers only

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[3] Logistics and Personnel Support, FMFM 4-1, Proposed Revision, MCDEC, September 1969.

TABLE 1 - DEFINITION OF ECHELONS OF MAINTENANCE

Level	Echelons	Maintenance and Distribution of Work
Organizational	First	Proper care of equipment; performed by equipment user, wearer, or operator.
	Second	Characterized as minor repair; performed by school-trained organizational personnel.
Field	Third	Characterized as component and assembly replacement. Piece-part replacement performed within limitations imposed by tools, test equipment, and repair parts authorized. Technical assistance to lower echelons included.
	Fourth	Characterized as component repair. Activities authorized a wider assortment of tools, test equipment, and repair parts than third-echelon activities. Technical assistance to lower echelons also provided.
Depot	Fifth	Highest echelon, characterized as industrial maintenance. Consists of overhaul, rebuild, fabrication, and manufacture. Provision of technical assistance to lower echelons included.

Source: Seaborne Mobile Logistic System (SMLS) Second Interim Report, Part 1, Joint CNO/CMC Study Group, August 1973.

2nd through 4th echelons of maintenance. Since first-echelon maintenance is accomplished by the equipment operator, and because items of equipment usually are not inoperative due to a requirement for first echelon maintenance, this echelon is not considered in the model. Because fifth-echelon maintenance requires extensive facilities, tools, technicians, and repair parts, it cannot normally be performed in the seabase or the field. In the model, any item requiring fifth-echelon maintenance is either stored or evacuated to a rebuild facility.

The organization of maintenance into echelons makes the determination of requirements for maintenance personnel, repair parts, maintenance equipment, and maintenance space to support various USMC organizations more straightforward. The required resources can be determined from the echelons of maintenance required by an organization and the number and type of end items in the organization. Furthermore, the echelon involved is an important variable in the determination of optimal maintenance configurations.

2.3 UNIT MAINTENANCE

2.3.1 Conventional Maintenance

The 34th Marine Amphibious Unit (MAU), an operational Marine Corps organization, serves to illustrate a conventional maintenance system. In this conventional organization, much of the maintenance required on the end items is performed by the MAU (the organization) itself; maintenance support is an integral part of the organization.

The MAU[4] is composed of various smaller units. (The general term "unit" can refer to a company, battery, or platoon each performing a specified individual function.) The units making up the 34th MAU (for the purposes of this analysis), and the highest echelons of maintenance they support, are listed in Table 2.

All maintenance work up to the level indicated in the echelon column can be performed; e.g., both 2nd and 3rd echelon maintenance can be performed at the LVT platoon. Maintenance support is performed by either a specific operational unit or by the LSU. A maintenance capability associated with a unit is referred to as organic to the unit.

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[4] Marine Corps Order No. 3120.3A, ltr A03H14-CC, 18 August 1970.

TABLE 2 - ECHELON REPAIR CAPABILITY

Unit	Repair Echelon Available In Unit
Rifle Co. (4)	no maintenance
Headquarters and Service Co.	2
Artillery Battery	2
Tank Platoon	2
LVT Platoon	3
Motor Transport Platoon	2
Engineer Platoon	2
Communications Electronics Platoon	2
Logistic Support Unit (LSU)	3

In any unit there will be a few types of items (known as overflow items) for which a second-echelon repair capability has not been provided. These items will be repaired by the LSU. All third-echelon work except that from the LVT platoon will also be sent to the LSU. The LSU, the centralized maintenance facility of the MAU, will repair most 3rd-echelon items, overflow 2nd-echelon items from the non-Rifle Co's and 2nd- and 3rd-echelon work from Rifle Co's. Rifle Companies perform no maintenance functions; as infantry troops they must remain mobile, and consequently they carry few end items requiring maintenance. Any requirement in the MAU for maintenance above the 3rd-echelon level cannot be fulfilled, and the item must be stored for maintenance at some later time.

2.3.2 SMLS Maintenance

Converting the 34th MAU to a pure SMLS configuration would require the following steps:

(a) Remove all 2nd-echelon capabilities from the units and locate with the LSU ashore,

(b) Transport the LSU to a seabase, and

(c) Add a 4th-echelon capability to the seabased LSU.

Step (b) would definitely have to be accomplished for the 34th MAU to function under the SMLS concept. Two questions arise: How far should step (a) be carried; i.e., what maintenance, if any, should remain with the units ashore and should step (c) be incorporated; i.e., is the gain in effectiveness due to increased capability worth the increased cost of resources required?

2.3.3 Application of the Maintenance Model

The Maintenance Optimization Computer Model was developed to answer such questions. The model is designed to be used as a tool in determining optimal SMLS maintenance configurations and in determining maintenance requirements in terms of personnel, maintenance equipment, and repair parts for these configurations.

The model allows a user to specify both location of maintenance and the highest echelon of maintenance to be performed at each location. If the seabase has the capability, it will repair only items from units which do not have a maintenance capability for a given repair echelon and commodity class (see Section 2.4). Failed items which require an echelon of maintenance not provided for in the seabase or ATF (as specified by the input) cannot be repaired and are discarded from the maintenance system. They are considered unoperational for the rest of the mission. At this time their repair outside the seabase is not considered.

Division of the landing force into units in the model makes it possible to investigate the effect of the availability of the end items (percent time operational) in each unit with and without organic maintenance. Also, a direct comparison can be made between the proposed seabased maintenance configuration and the conventional maintenance configuration as in the 34th MAU.

In order to evaluate proposed maintenance configurations under SMLS a baseline maintenance configuration was required. The 34th MAU was divided into units as illustrated in Table 2. This division resembles the present organization of the 34th MAU for the most part. Minor changes were made to facilitate analysis.

2.4 COMMODITY CLASSIFICATION

All the end items in the USMC inventory are classified by commodity class. The following commodity classes will be considered:

- Communications and Electronics (C/E)
- Engineer (Eng)
- Motor Transport (MT)
- Ordnance (Ord)

Every end item is listed in the Table of Authorized Material (TAM), USMC[5] and is identified by one letter followed by a four-digit number. The letter indicates the commodity class of the item and the four digits identify the item within the commodity class.

Thus an additional column for commodity class may be added to Table 2 (see Table 3). The entries in this column indicate the maintenance capability for each unit in terms of commodity class. Items in the commodity classes listed can be repaired by the unit, providing the echelon is 2 for all but the LVT Platoon and the LSU, where it is 3. When an item in a unit

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[5] Table of Authorized Material (TAM), Rev. 1, USMC, NAVMC 1017, 20 April 1970.

TABLE 3 - ECHELON AND COMMODITY CLASS MAINTENANCE CAPABILITIES IN THE UNITS OF THE 34th MAU

UNIT	ECHELON	COMMODITY CLASS
Rifle Co. (4)	no maintenance	
Headquarters & Service (H&S) Co.	2	MT, C/E, Ord
Artillery Battery	2	MT, C/E, Ord
Tank Platoon	2	MT
LVT Platoon	3	MT
Motor Transport (MT) Platoon	2	MT
Engineer Platoon	2	Eng
Communications Electronics Platoon	2	C/E
Logistic Support Unit (LSU)	3	MT, C/E, Ord, Eng

fails and the unit has no capability as listed in the last column in Table 3, the item is transported to the LSU for repairs.

The H&S Co. and the Artillery Btry. can repair all types of items except those of the Engineer commodity class. If the H&S Co. or the Artillery Btry. contains any Engineer items, they will be repaired by the LSU. In this application, however, all the Engineer items reside in the Engineer Platoon which has the organic maintenance capability required for those items. The Tank, LVT, and MT platoons contain only MT items and have the required maintenance capability; the C/E platoon uses and maintains only C/E items. The LSU has the capability to repair items of all four commodity classes. In this simulation allocation of end items in the 34th MAU requires the LSU to repair 2nd-echelon items from the Rifle Co's only.

In the conventional MAU, maintenance is performed only at the units; under SMLS, maintenance is also performed at the seabase. Generally, maintenance capability will consist of fixed shops, either at the seabase or at the unit, dedicated to a particular commodity class. Thus items belonging to the Engineer class will be repaired by an Engineer capability, Motor Transport items will be repaired by a Motor Transport capability, etc. Occasionally an item belonging to one commodity class will be repaired at the shop or unit involved with another commodity class whose maintenance functions are more in line with the item's requirements. For example, a tracked vehicle (LVT) belonging to the Ordnance Class could be repaired by Motor Transport when non-ordnance repair is required.

All maintenance done in the ATF is divided functionally according to commodity class, whether the maintenance is done in the seabase, at the units, or by contact teams (CT's) sent ashore from the seabase. There are separate shops in the seabase for maintaining the end items in each commodity class. CT's are sent from the relevant seabased shop only. For example, Motor Transport (MT) contact teams will be part of the MT shop and repair only MT items. Units ashore having organic maintenance capability repair only items for which they have a specified capability in terms of echelon and commodity class.

SECTION 3
MODEL DESCRIPTION

The maintenance model[2] has been designed according to the maintenance concepts covered in Section 2. Standard USMC maintenance operations and procedures have been followed as much as possible. Input and output and the overall model description are covered in this section. The detailed analysis used in the model is covered in Section 4.

3.1 MODEL INPUTS

The inputs to the model can be divided into four general categories:

- Maintenance system definition
- Landing force end item configuration
- Mission scenario
- End Item Data.

3.1.1 System Definition

The maintenance system is defined by echelon of maintenance required, number of contact teams* available, number of shop spaces, and maximum queue lengths. This information is read in as data. The entire maintenance system configuration is defined in the input and can be redefined for each computer run.

3.1.2 Landing Force End Item Configuration

The total numbers and types of all the end items ashore in the landing force requiring maintenance are read in as input. These end items are categorized in terms of the four commodity classes. Within each of these classes, the end items are categorized with respect to the unit they belong to. The end item lists are read in as input by commodity class and by unit. Replacement items located in the Operational Readiness Float (ORF) are also specified in the input but by commodity class only, not by unit.

3.1.3 Mission Scenario

Information describing the performance of the landing force and various

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* Maintenance personnel detached from the seabase to repair failed end items, see Section 5.3.

aspects of the maintenance system is specified in the mission scenario. The mission scenario includes the mission duration, transportation times between the seabase and units ashore, and a usage factor for each end item in the landing force. The usage factor specifies the number of hours an end item operates per day, except for ordnance items, where the usage factor is expressed in rounds fired per day. The usage of an end item depends on the type of mission (i.e., level of combat required) and directly reflects the nature of the mission of the landing force.

3.1.4 End Item Data

For each end item in the landing force it is necessary to provide reliability and maintainability data such as mean time between failures (MTBF) and mean time to repair (MTTR).

3.2 MODEL OUTPUT

The output of the model is considered in three categories:

- Availability
- Cost
- Utilization

3.2.1 Availability

The major effectiveness parameter computed in the model is end item availability which is defined as the average fraction of the mission time that a specified end item or group of end items is operational. The availability may be computed at the unit or force level by summing over all items in the force belonging to each of the four different commodity classes. The availability is a function of both the total time that items are operational and not operational, i.e., the downtime. Basically, the downtime is the total time that an item is not operational at the unit after failure because:

- The failed item is waiting for a replacement,
- the failed item is waiting for repair,
- the failed item has been discarded and no replacement exists.

The downtime and the availability are computed for the various levels as described below.

For example, let DT_{ij} equal the downtime in hours of the ith item in the jth unit over the mission duration, and MT equal the mission duration in hours.

If there are N units and M(j) items in the jth unit, then, for a given commodity class, the availability is given by:

$$\text{Availability} = \frac{MT - \sum_{j=1}^{N} \sum_{i=1}^{M(j)} DT_{ij} \Big/ \sum_{j=1}^{N} M(j)}{MT}$$

In the model, the availability is computed for all the items to be repaired for each of the four commodity classes and for all the items in the landing force, simply by changing the number of terms in the summation.

3.2.2 Cost

The cost of the maintenance system for each commodity class for a given configuration is defined in terms of

- the number of maintenance personnel required at the seabase,
- the number of CT and unit maintenance personnel,
- the maintenance equipment requirements for units, CT's, and seabase; i.e., the number of tool sets, kits, and special equipment required for repairing end items.

3.2.3 Utilization

Utilization is a measure of effectiveness which indicates the usage of maintenance personnel and the ability of the maintenance system to repair failed end items. It is defined as the fraction of the mission time that specified maintenance personnel are utilized in the seabase, at units, and as CT's. In addition, characteristics of the queues at the seabase, at units, and at CT's ashore are also computed. These quantities measure waiting times and occupancy in terms of number of items in the queues, indicating the degree to which the maintenance system performed its functions.

3.3 GENERAL ASSUMPTIONS

The following general assumptions were made to fully define the maintenance system:

(a) No sharing of maintenance resources among individual commodity classes,

(b) no 4th-echelon contact team repair,

(c) no 4th-echelon repair at units ashore,

(d) only ground maintenance considered; no aircraft maintenance is performed.

Assumption (a) represents the manner in which maintenance is presently performed. Maintenance performed for items of a given commodity class is done by utilizing personnel and equipment strictly dedicated to that commodity class. This assumption allows each of the four commodity classes to be simulated separately, rather than all at one time.

Assumptions (b) and (c) impose realistic conditions on the performance of maintenance. The scope of 4th-echelon maintenance makes it unlikely that it would be performed ashore by either units or CT's. A significant build-up of capability ashore would be required to perform 4th-echelon maintenance which is contradictory to the SMLS concept. In fact, the performance of 3rd-echelon maintenance would probably be limited for the same reason. Assumption (d), that requirements and operational procedures derived apply only to ground maintenance, is reasonable since in the USMC at present, air maintenance is separate from ground maintenance; they are considered two separate systems with individual resource requirements. Up to 3rd-echelon air maintenance is currently performed on LPH's and will be performed on the new LHA's. The performance of air maintenance has already been incorporated into a seabasing structure; therefore, under this task no effort was expended to integrate air and ground maintenance.

SECTION 4

MODEL OPERATION

The model simulates maintenance operation over the mission duration and produces availability and utilization figures. The availability represents the probability that the end items in the landing force are operational at any given time. It is a function of both the end item characteristics and the maintenance system configuration. The utilization measures the fraction of the time the maintenance system is being used in performing repair and is a function of the operation of the maintenance configuration. The cost values are computed during the input stage of the model.

To arrive at optimal maintenance solutions, the input is varied and the output parameters are examined. Such input quantities as number of ORF items, seabase and unit maintenance capabilities, number and type of CT's, and maintenance echelons specified at the seabase can be varied to optimize effectiveness and cost.

The computation of cost is relatively uncomplicated, requiring mostly direct arithmethic computation. The effectiveness measures, i.e., the availability and utilization parameters, are more complicated and are computed after running a number of replications in the model.

4.1 EFFECTIVENESS ANALYSIS

All end items are considered fully operational ashore at the beginning of the mission. During the mission, items fail and require repair. The types and locations of repairs required are determined from input information and conditions existing at the time of failure. An item may be repaired at a predetermined location, with or without being replaced, or the item may be unrepairable and have to be discarded or stored.

The operation of each item is simulated in the model by continuous failure/repair cycles generated throughout the duration of the mission. Several paths can be taken during the repair of each item depending on decisions of the following three types:

- Echelon of repair
- Location of repair
- Repair/replace/discard

4.1.1 Echelon of Repair Decision

When an item fails and the location of repair is determined, the failure is characterized by an echelon of repair which is generated through a probability distribution. (See Section 5.1.4 for a description of this process.) Maintenance of second through fourth echelons can be performed in the ATF.

4.1.2 Location of Repair Decision

In the ATF there are three possible locations for the repair of failed items:

- Unit
- Seabase
- Ashore by contact team

Under conventional amphibious operations, all required maintenance is performed at the unit. Some items can be repaired where they fail using maintenance equipment organic to the unit. Other items must be transported back to a centralized maintenance unit (i.e., the LSU) when they fail. The LSU receives items from most of the units in the landing force.

Under SMLS, when an item fails and the echelon of repair required is available at the unit (as specified by the input), the item is repaired. Units with any maintenance capability at all will normally be able to handle a 2nd-echelon repair. If higher than 2nd-echelon maintenance is required, the repair will generally be performed at the seabase, providing the required echelon of repair is available; if it is not, the item will be either discarded or stored. Maintenance up to the 4th-echelon can be performed at the seabase. If unit maintenance is not specified, CT's can perform up to 3rd-echelon repair ashore. Generally, CT's will perform minor repair and/or replace components.

4.1.3 Repair/Replace/Discard Decision

When an item fails ashore and is not operational, it is desired to minimize the downtime; i.e., the time the unit is without the item. The repair/replace/discard decision incorporated in the model simulates maintenance actions and is aimed at minimizing the downtime. Three alternative actions are possible:

- Repair without replacement,
- repair with replacement,
- discard with replacement (if available).

A failed item can be either repaired or discarded. The item is considered discarded when it cannot be repaired for operation during the mission. Actually the item is physically discarded only if it is beyond repair; it is stored for subsequent repair if the required echelon of maintenance is not available in the ATF or if 5th-echelon repair is required. Whether stored or discarded, it is considered in a "discard" status in the model.

If neither CT repair nor unit repair is specified, the item will be repaired at the seabase as soon as transportation and seabase shop space are available. If a replacement is available, it will be sent to the unit to replace the failed item. If no replacement exists, the unit operates without a replacement until the item is repaired.

The inventory of replacement items for the Landing Force (LF) is referred to as the Operational Readiness Float (ORF). The ORF levels can be continually in flux as items are drawn out when replacements are required and as items enter the ORF after being repaired but not required ashore. ORF items are specified for designated item types in the LF. If replacement items in the ORF are not specified, or if the inventory and the shops are out of an item requiring replacement, the unit does not receive a replacement during repair of a failed item. One of the objectives of the model is to minimize such a "stock out" by optimizing the ORF levels.

Replacements sent to a unit can come either from the ORF directly or from the shop after repair. The latter occurs only if the supply of the item in the ORF is exhausted and the required item is in the shop. The shortest downtime (accumulated time a unit is without a specific end item) is registered by utilizing a replacement from the ORF, the next smallest by utilizing items coming out of the shop as replacements, and the largest downtime when no replacements are available.

A repaired item will not necessarily be returned to the same unit. It may go either to another unit with a requirement outstanding, or to the ORF. Consequently, most units will not retain all the original end items they landed with.

4.1.4 Priority

In order to decrease downtime at the units and increase end item availability in the landing force, a priority system was incorporated in the model. An initial priority system considered was to assign priorities to each item failure. This would have entailed an evaluation of the seriousness of item failures and the degeneration of unit performance due to loss of the item. In other words, the scheme would have required the determination of which items were "combat essential". The difficulty of determining combat essentiality of each item in the landing force led to the use of a different scheme in the model. In this scheme, all items have the same repair priority when they fail, but the priority changes depending on whether the item is replaced and on the existing ORF levels. All items are assigned a priority of zero, the lowest, when they begin operating. Priorities may be upgraded when items first enter the seabase queue and may be upgraded a second time while the items are waiting to be repaired.

When ORF items are exhausted, the highest priority is assigned to those items waiting in the queue to be repaired which are required by units ashore. The second highest priority is assigned to items waiting for repair which, although not required ashore, are required to restock the ORF. In the first case, the ORF levels are considered to have reached zero before a replacement is required. In the second case the ORF level reaches zero when an item is withdrawn from the ORF. It is better, of course, to restock the ORF before an additional requirement causes a stock-out. The lowest repair priority is assigned to items which are not under either kind of demand.

The items in the queue are ordered by priority and time of arrival. The highest priority items will be taken first for repair. Since priorities are considered only when an item is in the queue, a priority will be reassigned only if an item fails again and re-enters the queue.

4.2 MAINTENANCE SYSTEM SIZING

Various alternate configurations were examined to determine the optimal SMLS maintenance configuration. These configurations can be defined by the following parameters:

- Location of repair - (at the seabase, at a unit, by CT)
- Highest echelon of maintenance performed at each location of repair - (2nd, 3rd, or 4th)

- Number of items which can be repaired at one time at each location of repair.
- Number of contact teams (CT) specified

When an item fails, the location of repair will depend on the unit the item belongs to, the commodity class of the item, and the echelon of repair required. The repair capabilities of the units and the seabase for a given configuration (including CT's) will be sized according to the number and type of items which need repair at each location. Generally, there is no interaction between personnel and resources of repair facilities of different commodity class; i.e., the facilities are independent of each other. This independence was assumed in the development of the maintenance model. Therefore, requirements for maintenance personnel and equipement are determined separately for each class. In addition, separate availabilities for the end items repaired in each commodity class are computed. The grade and military occupational specialty (MOS) of personnel required for maintenance are dependent on the types of items to be repaired as specified by present USMC maintenance policy. For each maintenance configuration and landing force, the simulation is run four times, once for each commodity class.

4.3 COST ANALYSIS

Availability and the utilization output parameters computed by the model are functions of the input configuration. These parameters indicate how well the maintenance system and the landing force perform their missions. Since increased effectiveness is usually gained through increased allocation of resources, i.e., increased cost, it is not feasible to maximize effectiveness without considering the costs involved. Generally, it is desired to obtain the greatest system effectiveness for the least system cost. Thus a measure of the cost of the maintenance system is required. Cost depends on the input maintenance system and is represented in the model by:

- Number of personnel required,
- Amount of maintenance equipment required.

Personnel required for conducting maintenance at specified locations (i.e., seabase, unit, or CT ashore) is determined in the model from an input matrix. This matrix is a function of commodity class and the highest echelon of repair available at locations of maintenance as specified in the input. The matrix elements specify the number of personnel per shift required to work on a given class of item. Thus, personnel requirements are computed for each commodity class.

The amount of maintenance equipment required is determined as a function of number, type, and maintenance location of each end item in the LF. A list of tool sets, kits, and special equipment required at each location of repair is generated.

SECTION 5
COMPUTATION OF MEASURES OF EFFECTIVENESS

Measures of effectiveness (MOE's) such as CT and shop utilization and queue statistics, which were discussed in Section 3.2.3, evaluate the performance of the maintenance system. Since the maintenance system repairs failed end items, and since the performance of the LF depends on the availability of these items, there is a close connection between the maintenance system effectiveness and the LF effectiveness. Availability is a function of the end item and maintenance system characteristics and measures the effectiveness of the maintenance system as well as that of the landing force.

In the model, failures and repairs, and actions such as transportation which result from failures, are simulated and the desired MOE's computed. Section 5.1 describes the calculation of availability and Section 5.2 describes other MOE's of the maintenance system.

5.1 AVAILABILITY

Availability is a measure of the degree to which items are operable and thus available for use over a specified mission time. The mission time less the total item operational time gives the non-operational time (downtime) for items during the mission. Non-operational time consists of times during which items wait for repair and for transportation, and times during which items are actually being repaired and transported.

To determine these operational and non-operational times, the basic simulation process incorporated in the model generates

1. Failures
2. Echelons of Repair
3. Locations of Repair
4. Transportation Events
5. Repairs

These events generate continual failure/repair cycles for each item for the duration of the mission, unless the item is discarded. Operational and non-operational times for each item are determined from the times involved in these failure/repair cycles, and availability is computed.

5.1.1 Monte Carlo Event Simulation

The Monte Carlo method is used to simulate the appropriate events and decisions. It involves picking a random number between zero and one, either from existing tables or by generating a random number by computer and interpreting this number in accordance with specific algorithms. In the simulation, the Monte Carlo approach is used to generate values for time to failure (TTF), time to repair (TTR), echelon of repair, and location of repair. The Monte Carlo process is thus used to generate the physical data required to simulate maintenance operation under the assumption that maintenance events will take place according to specific statistical distribution laws. The random number chosen in a given case is then interpreted in terms of these statistical distributions. This process is necessary because actual operational data are unavailable, i.e., extensive failure and repair data of USMC end items have not been recorded. MTBF's exist for only a few USMC items that are common to Army items. The remaining MTBF's required were developed by experts in the field. These data and the Monte Carlo process, together with the algorithms employed, permit generation of the parameters required for the simulation.

5.1.2 Derivation of Algorithms

The development of the algorithms that generate TTF's and TTR's by means of the Monte Carlo process is described below.

The MTBF's and MTTR's are physical parameters characteristic of a given type of end item and are invarient for a given environment. In order to obtain these parameters, it is necessary to observe the operation of the end items of that type over a period of time, referred to as the mission time. (This discussion will be limited to the MTBF, but the same reasoning holds for the MTTR.)

Every time the item fails, a record of the failure and the failure time is made. This record is kept for the entire mission. A suitable time interval Δt, is chosen and the mission time is divided into increments of Δt. The number of failures of items of a given type in each interval is determined, and a graph is drawn showing frequency of failure (number of failures occurring in each interval without replacement of failed items) in each time interval, as in Figure 1a. A smooth curve is drawn through these intervals (Figure 1b) with the functional form

$$F(t) = \lambda N_o e^{-\lambda t} \qquad (1)$$

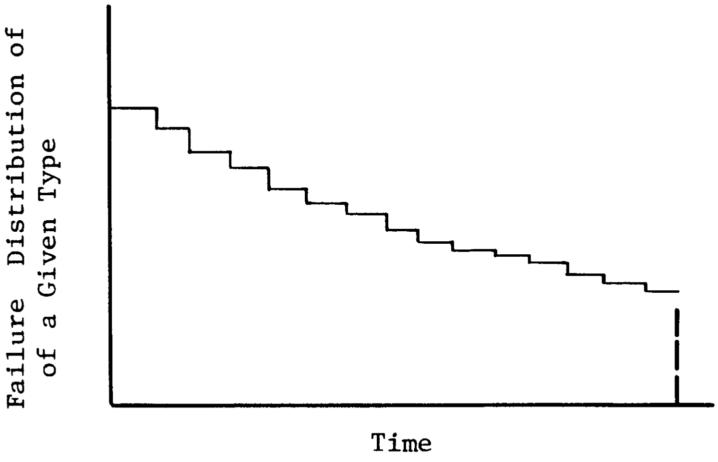

FIGURE 1a - FAILURE DISTRIBUTION

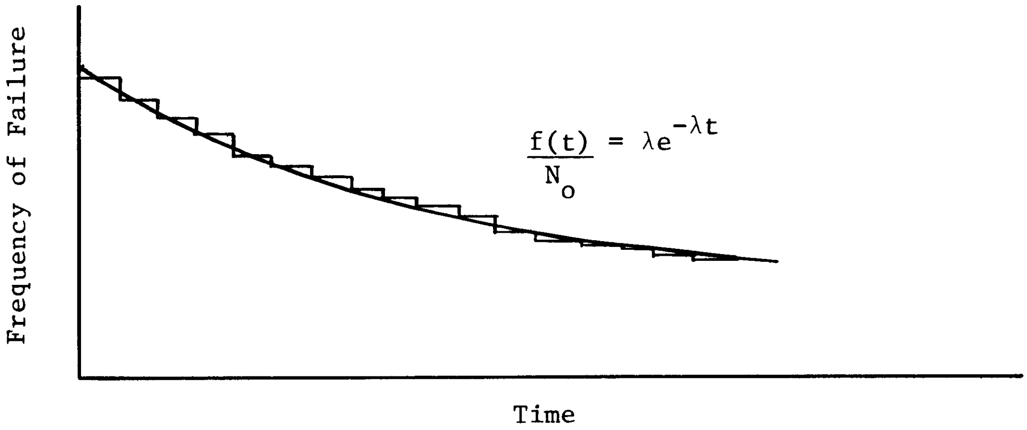

FIGURE 1b - EXPONENTIAL DISTRIBUTION

FIGURE 1 - EXPONENTIAL DENSITY FUNCTION FOR FAILURES OF A SPECIFIC TYPE OF ITEM WITHOUT REPLACEMENT

where t is the elapsed time represented by a given interval

λ is an empirical constant called the failure rate constant

N_o is the original number of items of that type

It can be shown that $\lambda = \frac{1}{MTBF}$ where MTBF is the mean time between failures for a specific type of item.

This curve is known as the exponential density function or exponential distribution and is characterized by a constant failure rate. This function adequately represents the operation of most electrical and mechanical systems.

The probability that an item will fail by time t_i is represented by the area under the curve up to $t = t_i$:

$$\text{Probability of Failure, } P[0, t_i] = \frac{1}{N_o}\int_0^{t_i} f(t)dt = \int_0^{t_i} \lambda e^{-\lambda t}\, dt \qquad (2)$$

$$\text{Integrating gives} \qquad P[0, t_i] = 1 - e^{-\lambda t_i} \qquad (3)$$

where t_i may be interpreted as a time to failure (at a given level of probability P). For the purpose of the simulation, we may generate realistically representative values of times to failure (TTF) for a given type of item as follows:

Rearranging Equation (3) we get

$$1 - P = e^{-\lambda TTF} \qquad (4)$$

$$\text{or} \quad TTF = -\frac{1}{\lambda}\ln(1-P) \qquad (4a)$$

Since values of (1 - P) lie between 0 and 1, we may use a random number generator to choose values of (1 - P) over this range. The value of r_1 (where $(1-P)=r_1$) is used to generate a TTF by Equation (4a).

$$TTF = -\frac{1}{\lambda}\ln r_1$$

Similarly, realistic Time To Repair values may be generated under the assumption that repair time values are also exponentially distributed. The repair rate constant (θ), such that $MTTR = \frac{1}{\theta}$, where MTTR is the Mean Time To Repair, is utilized in place of λ.

If a given item must operate 24 hours a day, then the above equation for TTF applies as given. However, rarely do items operate continuously; usually a daily operating period is specified. If a usage factor (U) specifies the number of hours an item operates per day, then

$$TTF = -\frac{24\ MTBF}{U} \ln r_1 \tag{5}$$

This formula assumes that the item is operational U hours per day. A usage factor which is usually a function of the mission is required for each type of end item.

5.1.3 Computation of Availability

In the formulas

$$TTF = -MTBF \ln r_1 \tag{6}$$

$$TTR = -MTTR \ln r_2 \tag{7}$$

r_1 and r_2 are random numbers between 0 and 1. These formulas are used to generate failure/repair histories; i.e., a set of TTF's and TTR's for an item as a function of the appropriate MTBF and MTTR values.

For example, Figure 2 shows a sample failure/repair history. In the figure the item begins operation at t_o and first fails at t_1; the time to the first failure is TTF_1. The time between t_1 and t_2 represents transportation time and other delays. The times between t_3 and t_4, t_5 and t_6, and t_7 and t_8 are of this same type. The item is repaired between t_2 and t_3; TTR_1 is the time for first repair. The item is operational at t_4, and at t_5 the item fails again and is repaired between t_6 and t_7. This failure/repair cycle continues until the end of the mission or until the item is discarded.

Failures and repairs are generated until the elapsed time t, becomes greater than or equal to the mission time, T.

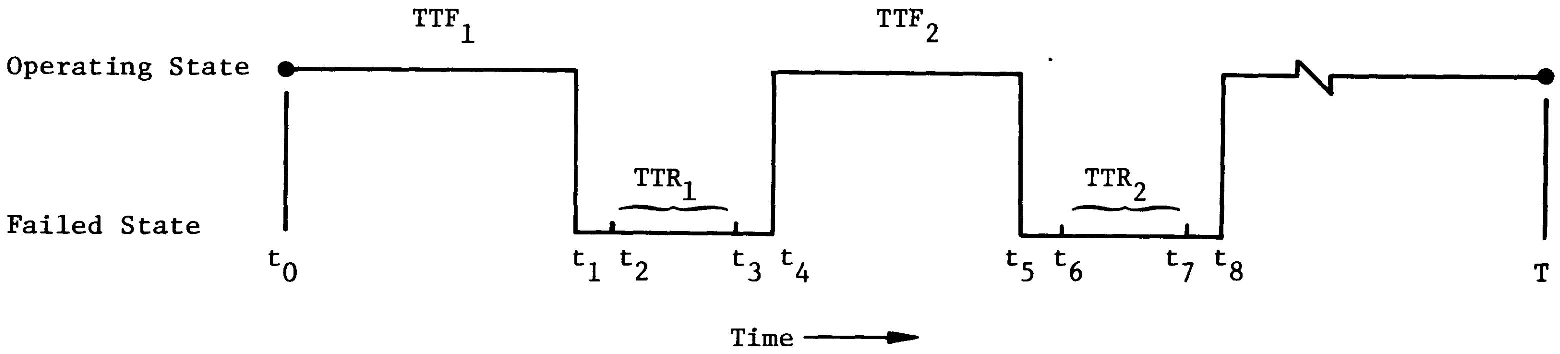

FIGURE 2 - FAILURE/REPAIR HISTORY FOR A GIVEN ITEM

$$\sum_{i=1}^{n} TTF_i + \sum_{j=1}^{m} TTR_j + \sum \text{transportation time} + \sum \text{delays} \geq T \qquad (8)$$

Transportation times and administrative and communications delays are input to the model. Delays due to items waiting in queues for repair are simulated in the model.

The elapsed time consists of the terms on the left of Equation (8). During the mission time T, n failures and m repairs were generated as were associated transportation times and assorted delays. The sum of all these events during the period from t=0 to t=T is known as a simulated mission. For each mission simulated and for each type of item the numbers n and m will vary due to the randomness of the process. Total transportation times and delays will also vary. The term $\sum_{i=1}^{n} TTF_i$ represents the total time the item is operational as indicated in Figure 2.

The total downtime, the time the item is not operational as defined in Section 3.2.1, is

$$DT = \sum_{i=1}^{m} TTR_i + \sum \text{transportation time} + \sum \text{delays} \qquad (9)$$

The downtime is a measure of effectiveness (MOE) of the maintenance system and is, of course, to be minimized. However, since it is a dimensional quantity, its value does not directly indicate system performance and does not allow comparison of different system configurations for different mission lengths. Consequently, another MOE, the availability, is used as the prime MOE. The availability, a nondimensional quantity, represents the percentage of the mission time that the item is operatonal and available for use. Thus

$$\text{Time Operational} = \sum_{i=1}^{n} TTF_i \qquad \text{and} \qquad (10)$$

$$\text{Availability} = \frac{\text{Time Operational}}{\text{Time Operational} + \text{Downtime}} \qquad (11)$$

Each simulated mission has a different set of TTF's and TTR's for each item, producing a different availability.

If k simulated identical missions (replications) are generated in a given run, then k availabilities are computed: $A_1 \ldots A_k$, where the A's have been summed over all the end items of the Landing Force for which maintenance is performed. These values are then averaged to give the total availability over k simulated missions

$$A_T = \frac{1}{k} \sum_{i=1}^{k} A_i \tag{12}$$

For a sufficient number of missions A_T converges. Section 7.2 discusses the determination of a sufficient number of simulated missions.

5.1.4 Repair Echelon and Failure Generation

When an item fails, four levels of maintenance action are possible. 2nd- 3rd- and 4th-echelon maintenance involve increasingly complex repair. The 5th-echelon or discard level signifies that the item is discarded from the maintenance system, either because it is beyond repair or because the required capability does not exist in the Task Force. The maintenance echelon required in any given instance is simulated through assignment of a random number R between 0 and 1 according to the following scheme:

$0 \leq R \leq a_1$	2nd-echelon repair required
$a_1 < R \leq a_2$	3rd-echelon repair required
$a_2 < R \leq a_3$	4th-echelon repair required
$a_3 < R \leq 1$	item discarded

The larger the range of values between a_i and a_{i+1}, the greater is the probability that the failure will require that echelon of repair. (The values of 'a' were determined from observation of actual failure data.)

Those echelons of repair available in the seabase are specified in the input to the model. For example, if the capability for only 2nd- and 3rd-echelon of repair is assigned to the seabase, requirement for 4th-echelon repair will cause the item to be discarded from the system. An item might also be discarded because it is beyond repair (5th-echelon), in which case it is either left ashore or transported to the seabase for selective parts utilization. In either case the failed item is not available to the landing force for the completion of its mission. Repair outside the seabase is not considered in the model.

When an item fails, the location of repair is also generated. The item can be repaired either by a CT ashore or at the seabase, depending on the value of the random number generated and on input values which specify the probabilities that the item will be repaired at the seabase or by CT.

For example, if b is the percentage of 2nd-echelon failures repaired by CT and R is a random number,

then $0 \leq R \leq b$ means the item is repaired by CT, and

$b < R \leq 1$ means the item is repaired at the seabase.

If the item required 3rd-echelon maintenance, a different value of b would be used. (The value of b was determined from actual failure data.)

5.1.5 Total Landing Force Simulation

In the model, the Landing Force ashore consists of a number of operational end items, each one with its own failure/repair cycle. Since many of these end items compete for the same maintenance facilities, there will be interactions among the failure/repair cycles of these items. Thus, downtime will be a function of the wait for maintenance in addition to the actual time to repair the item.

In the model, a time to failure is generated at time zero, the beginning of the mission, for each end item in the Landing Force ashore. The item is operational until the failure occurs. A transportation time is generated for each item in the order in which failures occur. When maintenance becomes available (at the end of the transportation time or when the item reaches the head of a queue), a repair time is generated. Cycles of failures and repairs are generated continuously in this manner for all items throughout each simulated mission.

Operational and repair times are computed and used together with transportation and delay times to give availability at the unit and commodity class levels. Other parameters such as queue characteristics and personnel utilization are computed over each simulated mission and averaged in the manner previously described to give final results over all the simulated missions.

5.2 MAINTENANCE SYSTEM MEASURES OF EFFECTIVENESS

The basic measure of effectiveness of the LF is item availability. In order to measure the effectiveness of the maintenance system and to evaluate the availability, quantities describing the capability of the maintenance system to perform maintenance on the end items of the LF are used. These quantities are determined for the queues associated with each location of repair and indicate the degree to which the maintenance facility at each location of repair was utilized.

5.2.1 Queue Description

The queues, or lines of items waiting to be repaired, are used to measure the response of the maintenance system and to help allocate resources. The characteristics of a queue indicate the capability of the repair location with which the queue is associated.

The first item in the queue will be the first one to be repaired unless a priority system is used. If the repair of some items is more important than repair of others, a priority scheme orders the higher priority items so that they will be placed in the front of the queue, thus decreasing their wait for repair.

Each location of maintenance in the ATF (unit, seabase, or CT ashore) is characterized by input parameters indicating the total number of items that can be repaired at one time. If a failed item arrives at the seabase or unit and a vacant maintenance space exists, repair of the item can be initiated immediately. If there is no vacant space, the item must wait until a space becomes free. If more than one item is awaiting maintenance at the same location, the items form a line or queue.

A priority scheme was utilized in the model to increase the efficiency of the system (see Section 4.1.4). All items have 0 priority initially. Any items assigned a priority of 1 or 2 move up in the queue. Items with a 2 priority become first in the queue; those with 1 next, and those with 0 are last.

For each unit ashore with organic maintenance capability and for the shops aboard the seabase, queues develop as required. Each commodity class shop can have its own queue. Three different repair echelon requirements (2nd, 3rd, and 4th) can be represented in a shop queue, since each shop can perform up to three echelons of repair.

If the queues aboard the ships exceed a specified maximum length (an input value), queues will be established ashore. When vacancies exist in the queues aboard ship, items from the shore queues will be transported to the ship. The characteristics of the queues ashore, i.e., the number of items which must be queued, will indicate the rate at which items are repaired by the shops aboard ship.

A CT queue for items waiting to be repaired by CT ashore will be established when required. The queue will form when the number of failed items requiring CT repair ashore is greater than the number of CT's available. In the model, CT's can be allocated in such a manner as to prevent long queues from being formed.

Items in the CT queue will not be physically transported when they fail but will be numbered in the order in which they fail. Hence, the CT queues merely specify the order in which the items ashore are to be repaired. As CT's become available, they will repair items at the head of the queue; i.e., those with the earliest failure times. (No priority system is used with the CT queue.)

5.2.2 Computation of Queue Performance Parameters

The following quantities are computed for each queue:

- Number of end items repaired
- Number of items entering queue during mission
- Maximum number of items in queue at any one time
- Average number of items in queue
- Average time item waits in queue
- Total hours queue exists

End items arrive at each queue and leave each maintenance location continually during the mission. The parameters above are computed for the seabase (and its queue ashore), for each unit, and for CT repair. These values are computed over each simulated mission during the operation of the model and are then averaged over all simulated missions.

The number of items repaired is equal to the number of items that have entered a maintenance space for repair after waiting in the queue. This parameter does not apply to the seabase queue ashore. The items leaving that queue enter the seabase queue afloat, not a repair space.

At each location of repair (seabase, unit, and CT ashore) the following quantities characterizing the repair of end items at that location are computed:

- Total end item repair hours (sum of all TTR's for items repaired at that location)
- Utilization of maintenance capabilities

5.3 FLOW CHART ANALYSIS

In the model, TTF's are generated for all the end items. The item with the earliest failure time is considered first. The process is diagrammed in the flow chart (Figure 3) on the following pages. The item is designated as coming from unit j and belonging to commodity class i. The echelon required for repair is generated for this item (kth echelon). Entry is made to the first three decision boxes [(1), (2), and (3)] to determine the echelon of repair required as described in Section 5.1.4. If the item is to be discarded and/or stored, a replacement (ORF item) will be requested at the unit. This process is accomplished through box FLOAT continued on page 35.

If 2nd- or 3rd-echelon repair is required, either box (4) or (5) as appropriate is entered to determine whether repair at unit j is specified at these echelons. If unit j has been assigned a maintenance capability at the required kth echelon, the failed item will proceed to the unit queue and be repaired, represented by boxes Repair Unit j(2) or Repair Unit j(3), whichever is required. If unit j is not assigned the required maintenance capability, either decision box (7) or (8) is entered to determine whether 2nd and 3rd echelons of repair are specified at the seabase. If so, box E(2) is entered when 2nd-echelon repair is required and E(3) when 3rd-echelon repair is required. In either case, the item is repaired at the seabase. If the failure requires 3rd-echelon maintenance and only 2nd-echelon capability was assigned to the seabase, or if the failure was either 2nd- or 3rd-echelon and neither was assigned to the seabase, the failed item is discarded or stored and a replacement at unit j is required. No 4th-echelon repair is allowed at the units, but if

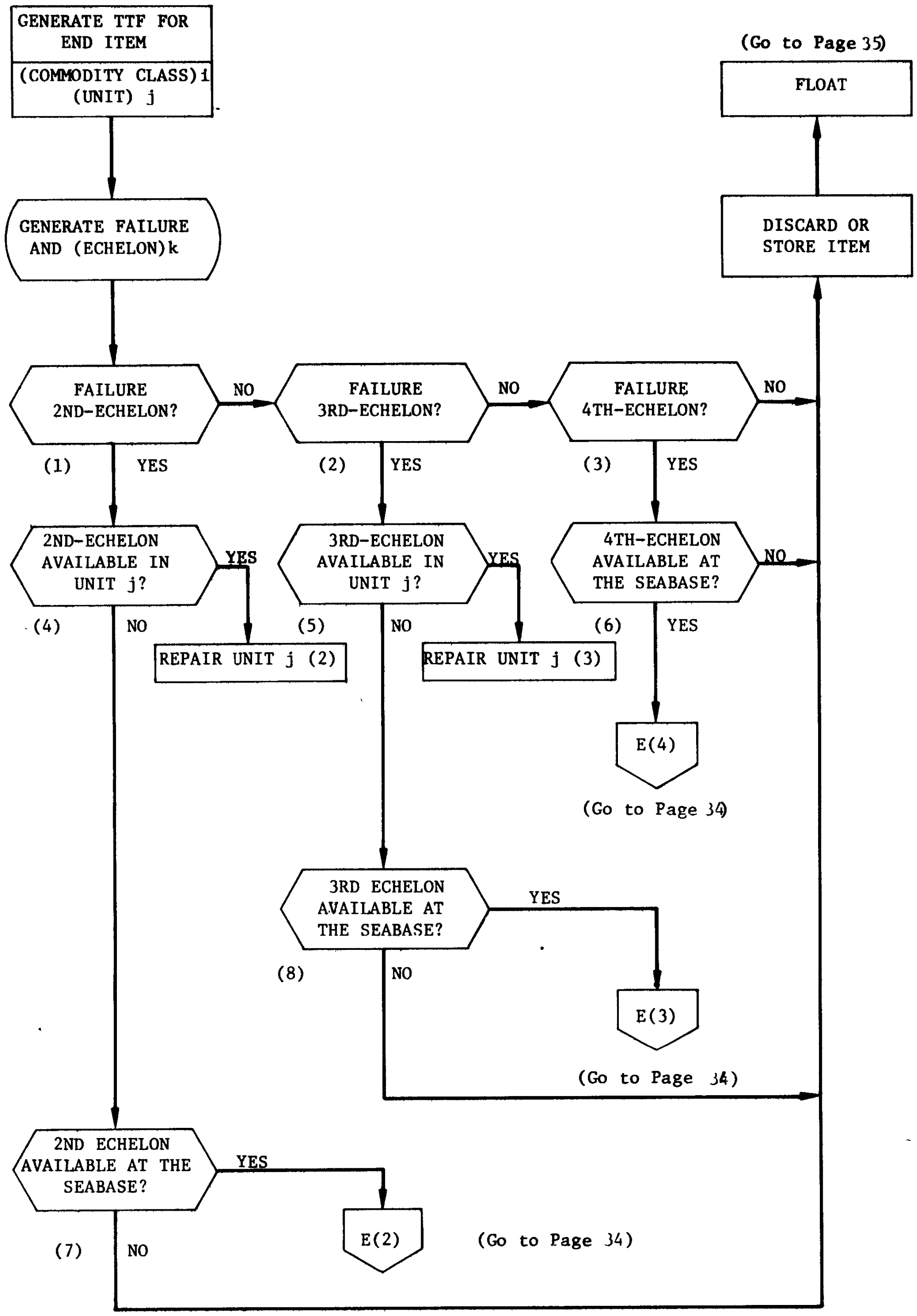

FIGURE 3 - MAINTENANCE MODEL LOGIC FLOW

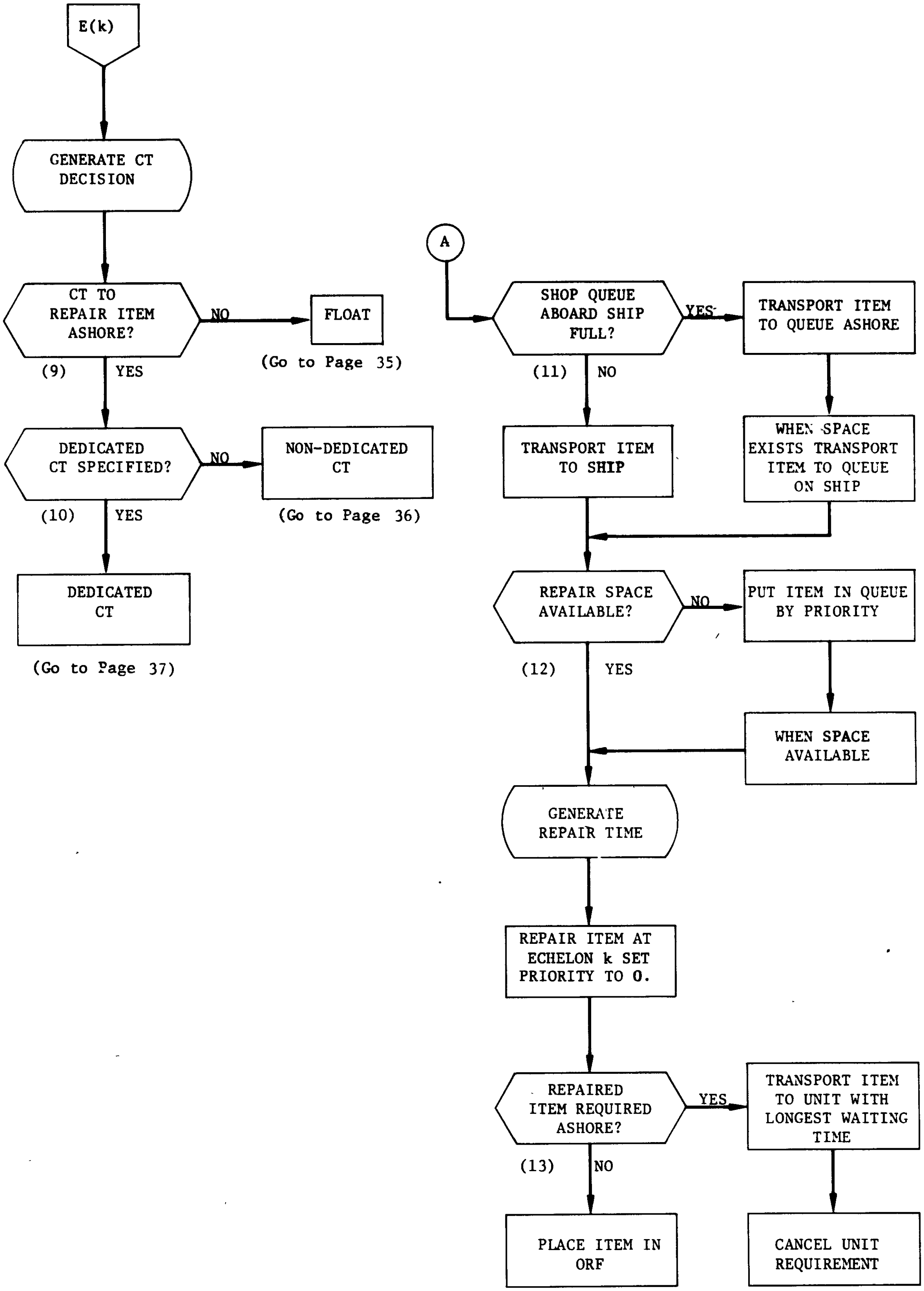

FIGURE 3 - (Cont'd)

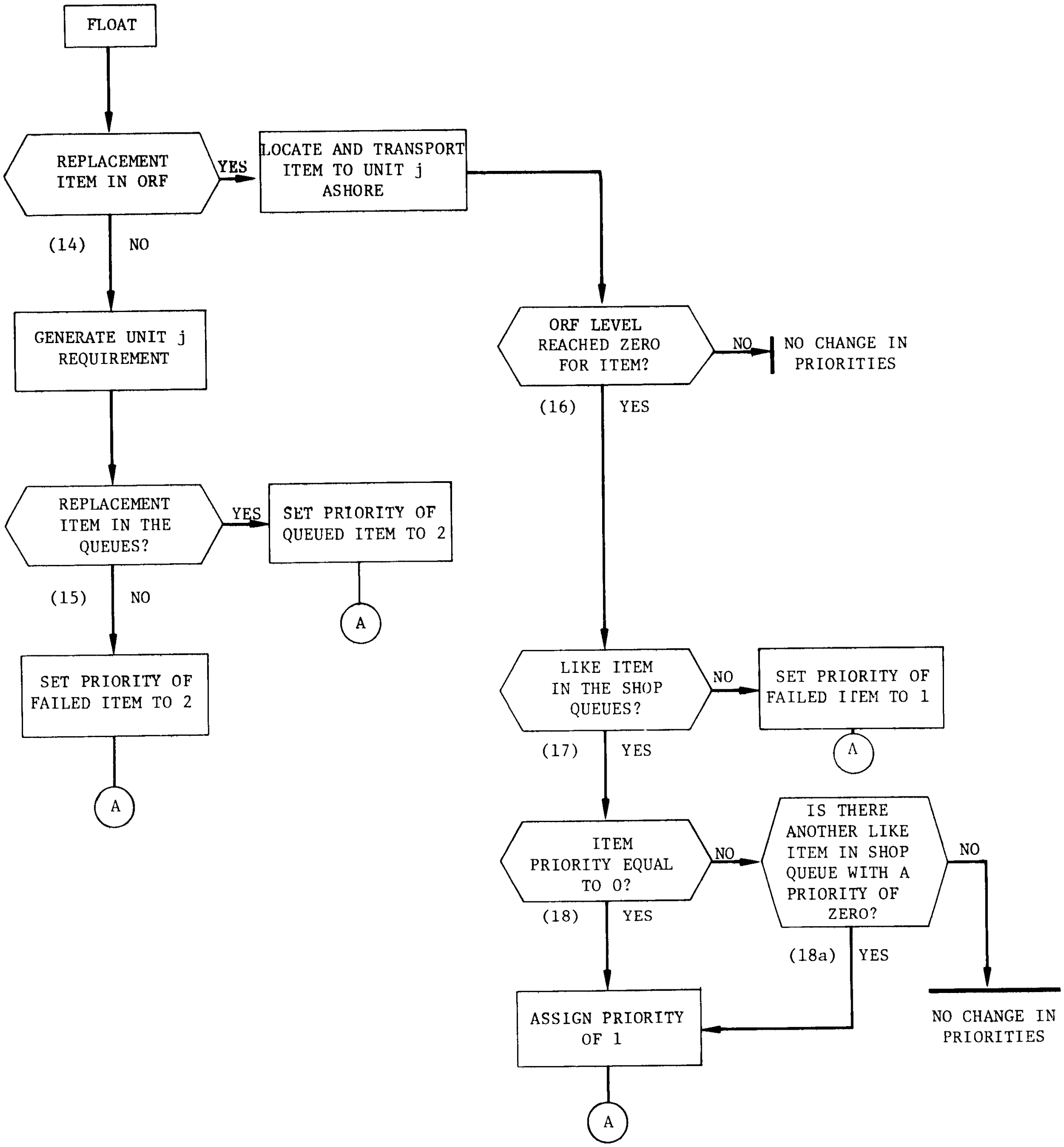

FIGURE 3 - (Cont'd)

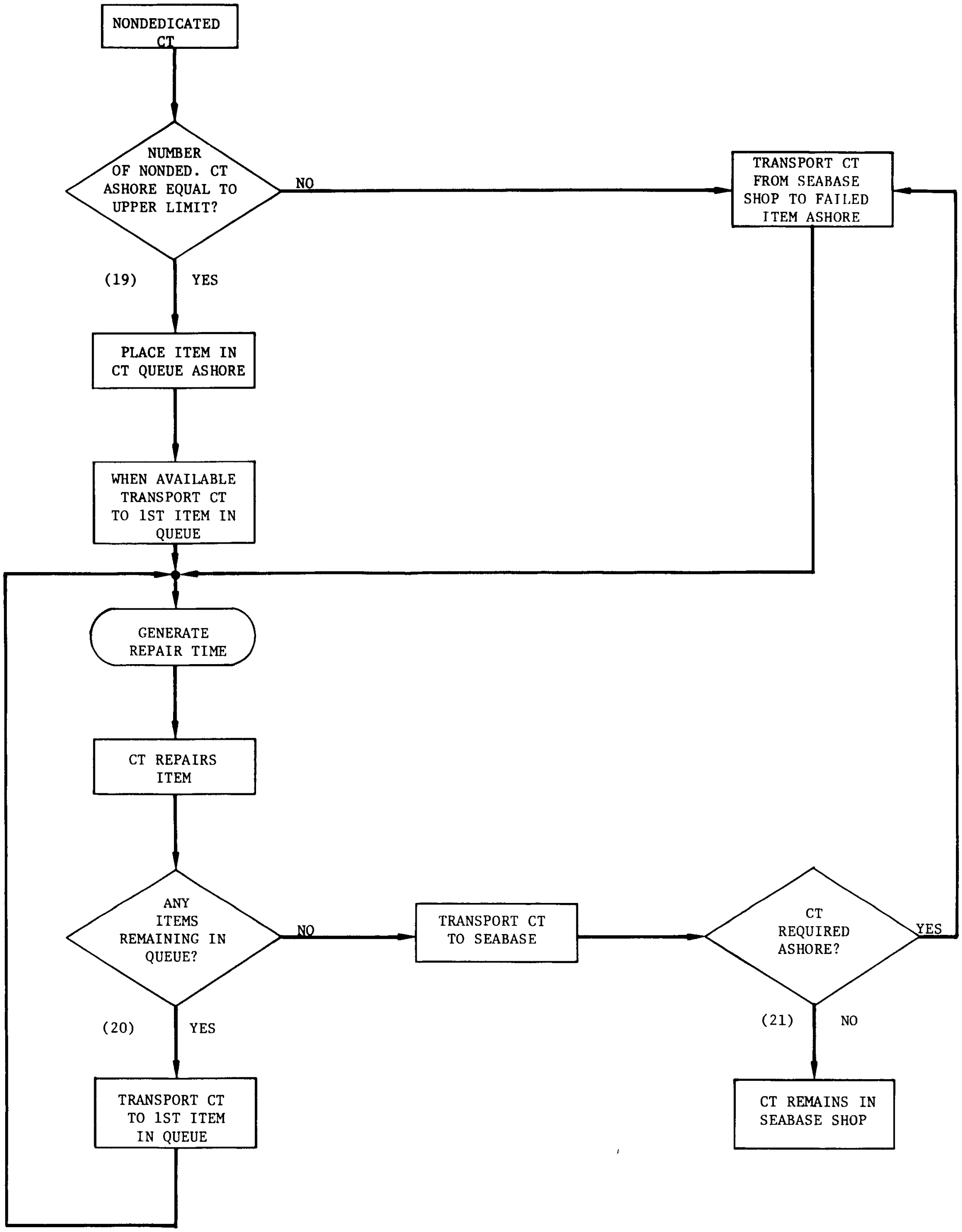

FIGURE 3 - (Cont'd)

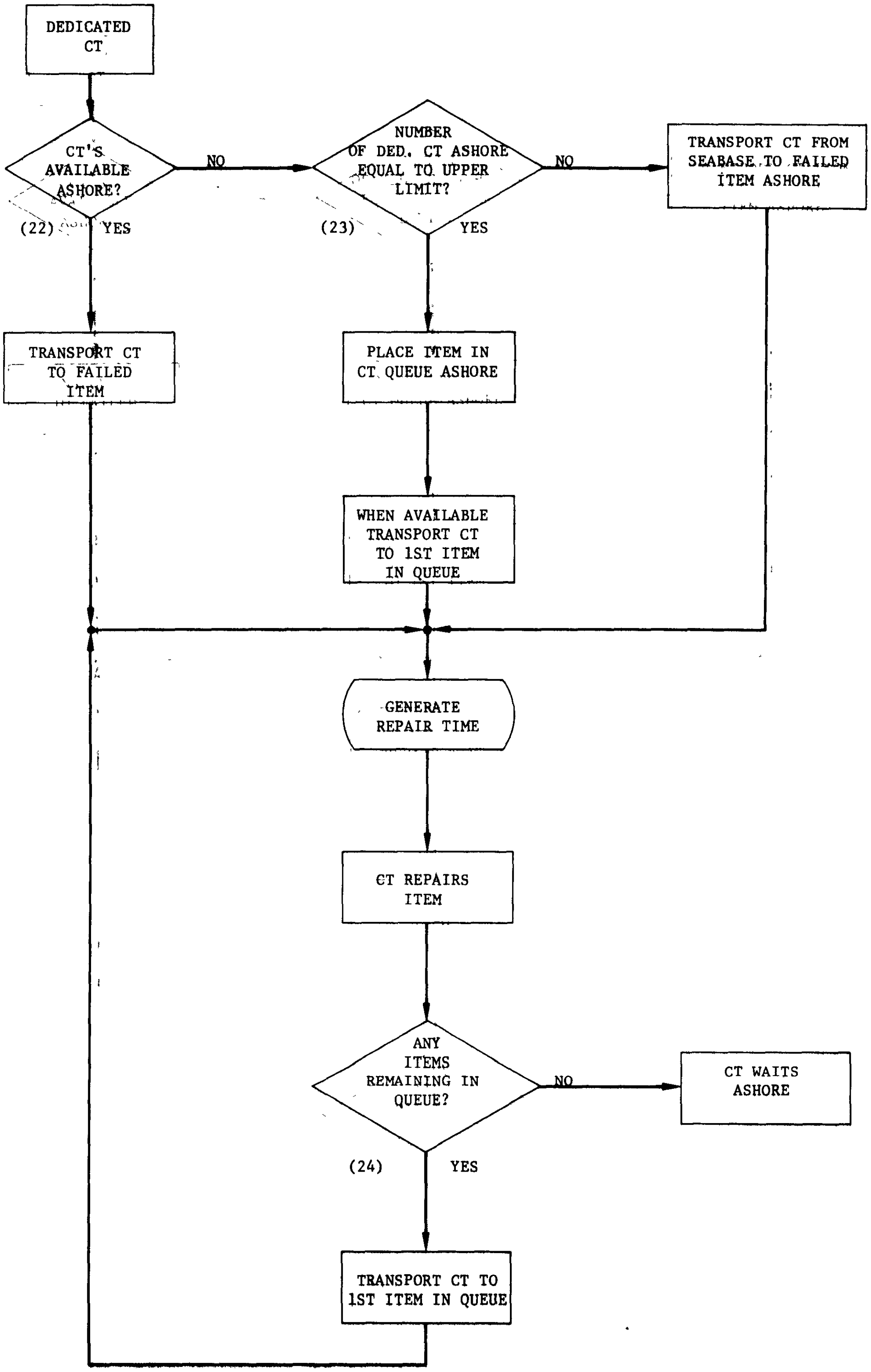

FIGURE 3 - (Cont'd)

4th-echelon is required, decision box (6) is entered to determine whether 4th-echelon capability has been specified at the seabase. If it has, entry to box E(4) is made for 4th-echelon repair. If 4th-echelon has not been specified, the item is discarded or stored and a replacement is required at unit j.

Boxes E(2), E(3), and E(4) represent repair at the seabase at the echelons corresponding to the numbers in parentheses. The echelon of repair required is generalized by referring to all seabase repair as E(k) on page 34. The value of k represents the echelon of repair required. If CT's are specified in the input, the decision on whether CT's or the seabase will repair the item is made in box (9) where a random number is generated to determine whether CT's are to be utilized. This decision is made on a probabilistic basis as described in Section 5.1.4.

If CT's are not specified in the input, the decision at box (9) is automatically "no". If a CT is to be used, decision box (10) is entered to determine whether a dedicated or non-dedicated CT is to be used. (When CT's are specified, either dedicated or non-dedicated CT's must be specified in the input, but not both.) A non-dedicated CT represents maintenance personnel who are an integral part of the seabase work force. They are detached to the shore to repair failed items. When a non-dedicated CT leaves the shop, capacity in terms of the number of items that can be repaired at one time could be degraded. On the other hand a dedicated CT is not part of the shop personnel; i.e., these personnel have no collateral duties aboard ship. When they leave the ship, no decrease in the shop capacity occurs. The decision as to the type of CT to be used is based on input specifications. The CT flow continues on page 36 or 37 as required.

If a CT is not specified or cannot be used, the flow enters box FLOAT to obtain a replacement for the failed item and to assign priorities. The flow in box FLOAT continues on page 35. Decision box (14) is entered to determine whether a replacement for the failed item is in the ORF. If a replacement item does not exist in the ORF, the failed item will be repaired at the seabase without being replaced at the unit. Since in this instance an item left the unit without being replaced, a unit requirement is generated in the program indicating need for a replacement. Once the replacement requirement for unit j has been generated, the shop queues are examined (15). If an item of the desired type is found in a queue, its priority is set to 2 if it is not already at that level. This process can shorten the wait for maintenance, thus decreasing downtime. Since downtime at the unit increases when replacements are not available, failed items should be repaired as quickly as possible. If an item of the desired type is not found in the queue, the priority of the failed item itself is changed from 0 to 2 to allow repair as early as possible and to reduce downtime. Items with the same priority in the queue are ordered by arrival time.

If decision (14) indicates that an ORF item is available, it is issued, transported to unit j ashore, and becomes operational. Since this item is now part of the landing force, it can eventually fail and the entire failure/repair cycle repeats. When an ORF item is issued, the inventory is updated and the ORF level for that type of item is tested (16) to determine whether it has reached zero. If it has and there are no items of the same type waiting in the shop queues (17), the failed item is assigned a priority of 1 (the second highest). This priority can decrease the waiting time for repair of the item and hasten the replenishment of the ORF. If the inventory level becomes zero and there is an item of the same type in the seabase queue with a priority of 0 (18), that item is assigned a priority of 1. If the priority of the like item in the shop is not 0, a search is made (18a) for another like item with a priority of 0. If one is found, its priority is set to 1; otherwise, no changes in priorities occur.

The flow between (9) and (11) on page 34 was interrupted by the flow to FLOAT. The flow resumes at (11) to determine whether the queue aboard ship is full. If it is not full, the item is transported to the seabase. If a repair space is available (12), the item can be repaired immediately at echelon k. (A repair time is generated from an exponential distribution.) If no repair space is available (number of items in the queue is greater than an input value), the item will be queued aboard ship to wait for a shop vacancy. If at decision (11) the shop queue is full, the item will be queued ashore until there is a space in the shop queue. Once aboard ship, the item follows the flow described above, i.e., the flow enters box (12).

After repair, the priority value of the item is set to zero if it is not already zero. If the item is not required ashore, (13), it is placed in the ORF. If the item is required ashore, it is sent to the unit with the earliest maintenance request outstanding for that item type. When the item reaches the unit, the unit requirement is cancelled and downtime stops.

Pages 36 and 37 deal with the contact team (CT) analysis. An input value examined in decision box (9) specifies whether a CT is required, and if so, whether it is to be dedicated or non-dedicated (10). Page 36 shows the non-dedicated CT analysis. If the number of non-dedicated CT's already ashore is less than a limit specified in the input (19), a CT can leave the ship when personnel become available. If all maintenance personnel are occupied, the CT cannot be sent immediately. Non-dedicated CT's are taken from the shop work force and there is a limit on how many can leave the shop. This limit prevents a decrease in shop personnel to the extent that shop capability is degraded to an unacceptable level. When personnel become available, the CT leaves the ship. At that time, the shop capacity may decrease, depending on how many non-dedicated CT's have left the ship.

After leaving the ship, the CT is transported ashore to the failed item. (A repair time is generated from an exponential distribution.) Meanwhile, other items may have failed, forming a CT queue ashore. If there is such a queue (20), the CT, after repair of the original item, proceeds to the first item in the queue. If no queue was formed, the CT is transported back to the ship.

If the number of CT's ashore is equal to the specified limit (19), no additional CT's are available for repair and failed items are queued ashore to wait for an available CT. The items will be repaired in the order in which they have been registered in the queue. When no more items require maintenance (20) (i.e., the CT queue is empty), the CT is transported back to the ship. When it arrives, personnel return to the shops if no new requirements ashore have arisen (21). The arriving CT may then increase the capability of the shop.

Page 37 covers the dedicated CT analysis. First, a test is made of the availability of dedicated CT's ashore (22). If none are available to repair the failed item ashore (all occupied), a test is made to determine whether the upper limit on the number of CT's has been reached (23). If it has, the item is placed in the CT queue and will be repaired when it reaches the front of the queue and a CT is available. If the upper limit has not been reached (23), a CT is transported ashore to repair the item. If dedicated CT's are already available ashore to repair the failed item (22), one is transported to the failed item. After repairing this item, the CT will be transported to the first item in the queue, providing the queue is occupied (24). If no items require repair, the dedicated CT will proceed to the nearest unit and wait for the next assignment.

SECTION 6
COST METHODOLOGY

If measures of effectiveness based on performance were the only criteria used in the development of maintenance systems, the final design might have unacceptably high system costs. It was therefore necessary to incorporate into the model the ability to determine maintenance system costs. Such costs are represented in the model in terms of number and type of resources required rather than as dollar costs.

The model is designed to determine (a) the resource cost of a given system effectiveness, and (b) the configurations for which the least resource cost will produce the most effectiveness. Factors considered in determining the cost of producing a given effectiveness include requirements for personnel, tools, and test equipment.

6.1 PERSONNEL

Personnel represent one of the most important resources required in the maintenance system. However, the lack of organized information and the difficulty of quantifying personnel actions make personnel requirements most difficult to predict.

The matrix shown in Table 4 specifies the number of maintenance personnel required to work at a given time on a single item in each commodity class as a function of repair echelon. For instance, one person is required to work on a Motor Transport item if repair is required at 2nd-echelon. If the item requires either 3rd- or 4th-echelon repair, two people are required.

The capacity of shops for each commodity class is input as the number of items such shops can repair simultaneously. The highest echelon of repair performed at the shop is also specified in the input. For each shop the capacity is multiplied by the appropriate element from the personnel matrix. For example, if two men are required to work on a Motor Transport item at the 4th-echelon level and the shop capacity is 2, then 2 x 2 = 4 people are required in the shop.

If the shop has a maintenance capability specified at 4th-echelon, it

TABLE 4 - NUMBER OF PERSONNEL REQUIRED TO REPAIR ITEMS AT THE SEABASE AS A FUNCTION OF COMMODITY CLASS AND REPAIR ECHELON

Repair Echelon Commodity Class	2	3	4
Comm/Elec	1	1	1
Engineer	1	2	2
Motor Transport	1	2	2
Ordnance	1	1	2

can also perform 2nd- and 3rd-echelon work. Personnel requirements depend on the highest echelon of maintenance performed at the shop, since this represents the upper limit of personnel requirements.

The personnel requirement computation is performed during the input stage of the model. After the model has been run for a specified number of simulated missions, the total end item repair hours for each shop is computed. This figure represents the total repair time (TRH) for all items repaired in the shop.

Utilization of shop personnel U_P, is determined by the following relationship:

$$U_P = \frac{TRH}{SC \times MT} \tag{13}$$

where TRH is the total end item repair time in hours

SC is the shop capacity, and

MT is the mission duration in hours

The interpretation of U_P is dependent on the number of shifts specified.

In the model, maintenance actions are simulated for a full 24 hours a day, implying that the shop can work continuously. If personnel are in the shop all the time, full personnel utilization would be $U_P = 1.00$. Since this would mean that personnel were working continuously with no breaks, the following assumptions were made:

- Useful output is 8 hours a day for maintenance personnel
- Shop-utilization ranges inply numbers of shifts as follows:

Utilization	Number of 8-Hour Shifts Required Per Day
0 to 0.33	1
0.34 to 0.66	2
0.67 to 1.00	3

The second assumption is based on the following reasoning. If a shop operates 24 hours a day and the personnel are not utilized more than 33% of the time, the same work could be handled completely by these same personnel in one 8-hour shift. Although, of course, items fail over the entire 24-hour period, if the shop operation over many days is considered, one shift could keep the assigned items in operating condition. Similarly, if the utilization values were between 0.33 and 0.67, two 8-hour shifts would be required and the shop would be open 16 hours a day. As in the earlier example in the Motor Transport shop where 2 x 2 = 4 people were required, this would mean 4 people per shift.

If two shifts were necessary, 2 x 4 = 8 people would be required. Model runs indicated that most of the shops in the seabase required two shifts except for the Engineer shop, which required only one.

6.2 MAINTENANCE EQUIPMENT

Whenever a repair capability is required, an assortment of maintenance equipment (i.e., tool kits and test equipment specifically tailored for the end items to be repaired) is required. The number and type of tool kits and maintenance equipment are functions of the number and type of repairable items with which the MAU embarks.

From data collected at Marine Corps Headquarters for three of the four commodity classes, decision rules were developed for use in the model. The results are in the form of a table specifying name and number of maintenance equipment required at each location of maintenance.

The maintenance equipment (i.e., tool sets, kits, and special equipment) for the Motor Transport class is more specialized than for the other classes. The maintenance equipment items were categorized as to whether they applied to vehicles or trailers, and whether the vehicle had gasoline or diesel engines. Each item of maintenance equipment is described by the number of vehicles or trailers it can repair at each repair echelon. Some equipment can be used at only one repair echelon; other equipment can be used at more than one echelon. Some maintenance equipment items were required by specific end items, but the majority were used more generally.

The items of maintenance equipment associated with the Engineer and Communications/Electronics classes were apportioned on the basis of the maintenance capability required.

SECTION 7
ACCURACY OF RESULTS

The logic and decision rules in a simulation model attempt to represent the real physical world. However, such a representation is only as good as the data used, and in most applications the accuracy of the data, if the data exist at all, is much lower than required. A sample sensitivity analysis was performed to determine the sensitivity of the results obtained using this model to the accuracy of the input data; i.e., the effect of input accuracy on output accuracy. The number of replications, i.e., the number of simulated missions required to produce a specified precision in the results, was also investigated.

7.1 SENSITIVITY STUDY

Since MTBF was the most important type of data element, it was used in the sensitivity study performed to test the effect of accuracy of input assumptions.

Table 5 shows the variations in the downtime of item D1100, a half-ton platform truck of the Motor Transport (MT) Class, with variation in the MTBF. Of a total of 199 items in the MT class, 26 were of the D1100 type. The values of the downtime were determined by averaging the results of several runs to obtain a more accurate figure.

The results show that an average change of 36.5% in the MTBF produced an average change of 11.5% in downtime. This item in the MT class is thus relatively insensitive to change in MTBF, even though it represents 26/199 x 100 = 13% of the items in that class. Consequently it can be concluded that, within the range used, the actual value of the MTBF of D1100 is not overly significant.

7.2 NUMBER OF SIMULATED MISSIONS REQUIRED

The feasible number of replications, i.e., simulated missions, to be run in the model is constrained by two factors:

(a) dollar cost of computer running time

(b) accuracy of results

As the number of simulated missions increases, both of these factors

TABLE 5 - VARIATION OF DOWNTIME AS A FUNCTION OF MTBF

Run (i)	MTBF (hr)	Downtime (hr)
1	75	306
	$\Delta_{MTBF} = -0.40$	$\Delta_{DT} = 0.11$
2	45	341
	$\Delta_{MTBF} = -0.33$	$\Delta_{DT} = 0.12$
3	30	383

Average $\Delta_{MTBF} = 36.5\%$ Average $\Delta_{DT} = 11.5\%$

where $$\Delta_{MTBF} = \frac{MTBF_{i+1} - MTBF_i}{MTBF_i}$$

$$\Delta_{DT} = \frac{Downtime_{i+1} - Downtime_i}{Downtime_i}$$

increase. Ideally cost is to be minimized and accuracy maximized. This optimization requires determining the minimum number of simulated missions that will give the required accuracy. If this minimum number of missions involves unacceptably high computer costs, a re-evaluation of the model will be required.

Two procedures are presented for determining the number of replications required. The first, an empirical procedure, examines the difference between the value of an output parameter in a given run and the value of the same parameter for a large number of replications. The second procedure is theoretical and computes an accuracy measure based on standard deviations. Although the theoretical procedure was used in all computer runs, the empirical procedure is presented because it illustrates the effect of the number of replications on output parameters.

7.2.1 Empirical Procedure

Table 6 summarizes the computer runs. Two output parameters are given: downtime of all Motor Transport (MT) items in the landing force, and utilization of the seabase MT maintenance shop in percentage of mission time. These parameters were chosen on the basis of their importance in analyzing the results. It was assumed that the value of a given parameter resulting from a run consisting of a specific number of replications would converge to a truly representative value as the number of replications became large.

The first column in Table 6 gives the number of replications or simulated missions for which computer runs were made. The values of the two parameters for each run represent a cumulative average over all previous replications. These values were plotted against the number of replications per run in Figure 4, and downtime and utilization curves were obtained by fairing through the plotted points. The asymptotic value of the downtime curve was 738 hours; the asymptotic value of the utilization curve was 47.1%.

The fractional difference of each data point from the corresponding asymptotic value given in Table 6 was then computed and plotted in Figure 5 against the number of replications.

The computer run at 200 to 300 replications, where the fractional differences are about 1%, represents an optimum number of replications.

TABLE 6 - MOTOR TRANSPORT ITEM DOWNTIME AND SHOP UTILIZATION FOR VARIOUS NUMBERS OF REPLICATIONS

NUMBER OF REPLICATIONS	ITEM DOWNTIME (DT) IN HRS	FRACTIONAL DIFFERENCE OF DT FROM DT_∞	SHOP UTILIZATION (U) IN %	FRACTIONAL DIFFERENCE OF U FROM U_∞
50	790	0.070	45.7	0.030
100	774	0.049	44.7	0.051
200	748	0.014	47.6	-0.010
300	746	0.011	46.9	0.005
400	731	-0.009	46.3	0.017
500	745	0.009	47.1	0
600	737	-0.001	47.1	0
700	743	0.007	47.1	0

Asymptote of Downtime Curve, DT_∞ = 738 hrs

Asymptote of Utilization Curve, U_∞ = 47.1

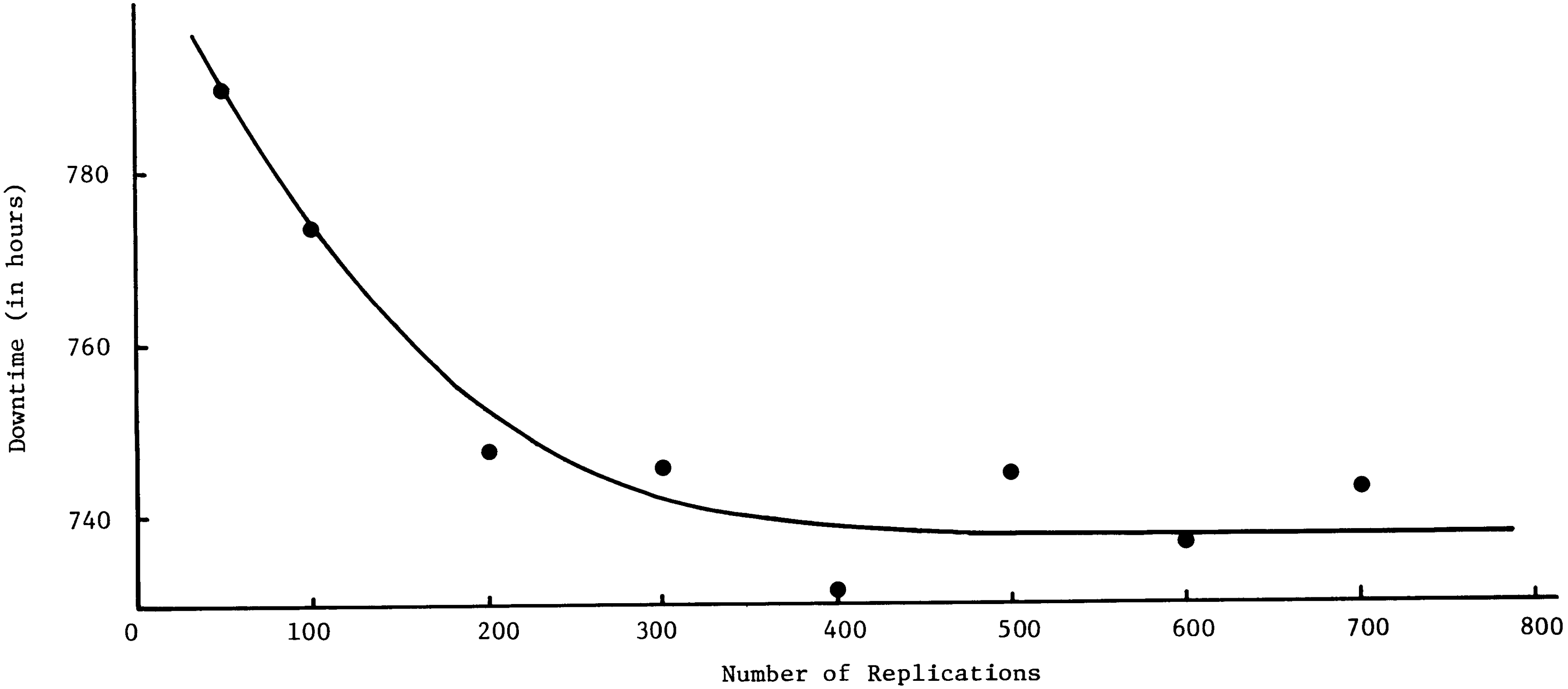

Figure 4a - Determination of Asymptotes for Downtime

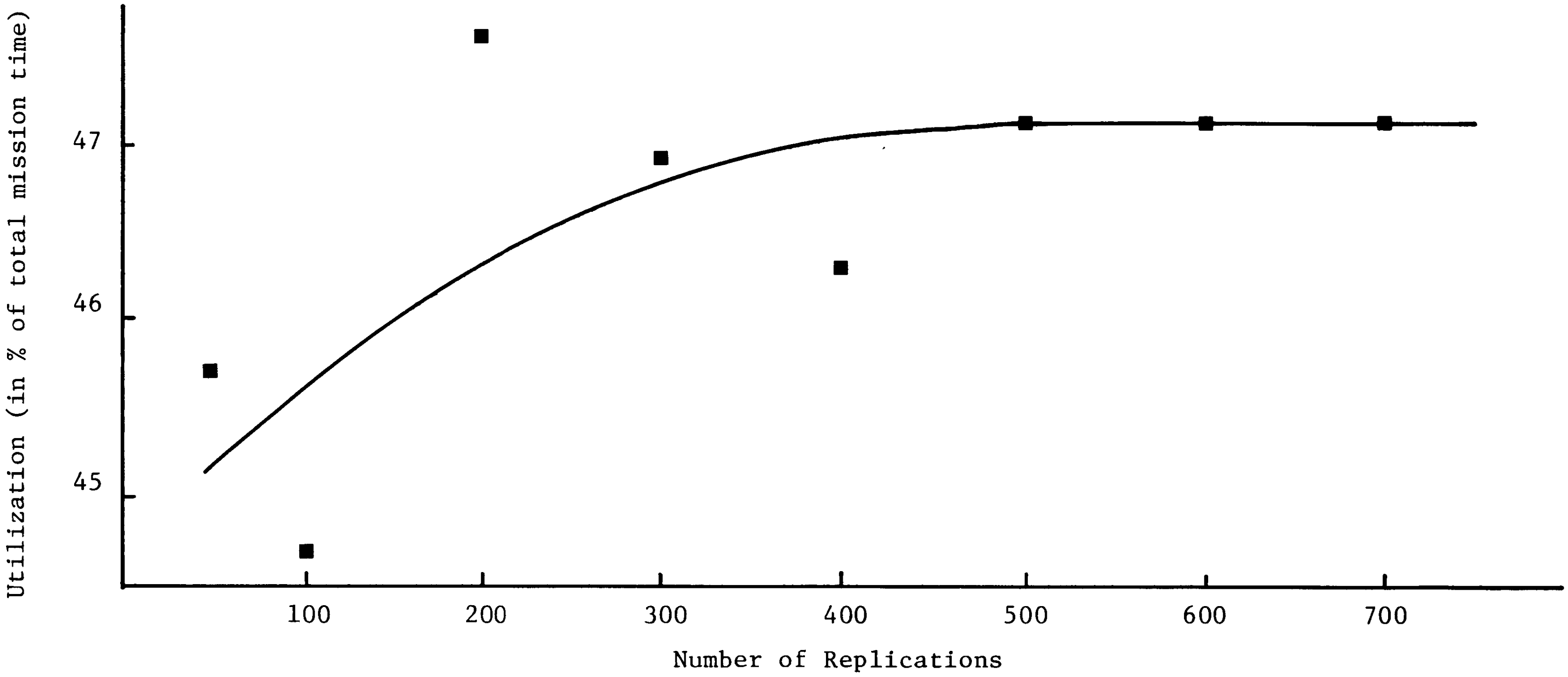

Figure 4b - Determination of Asymptotes for Utilization

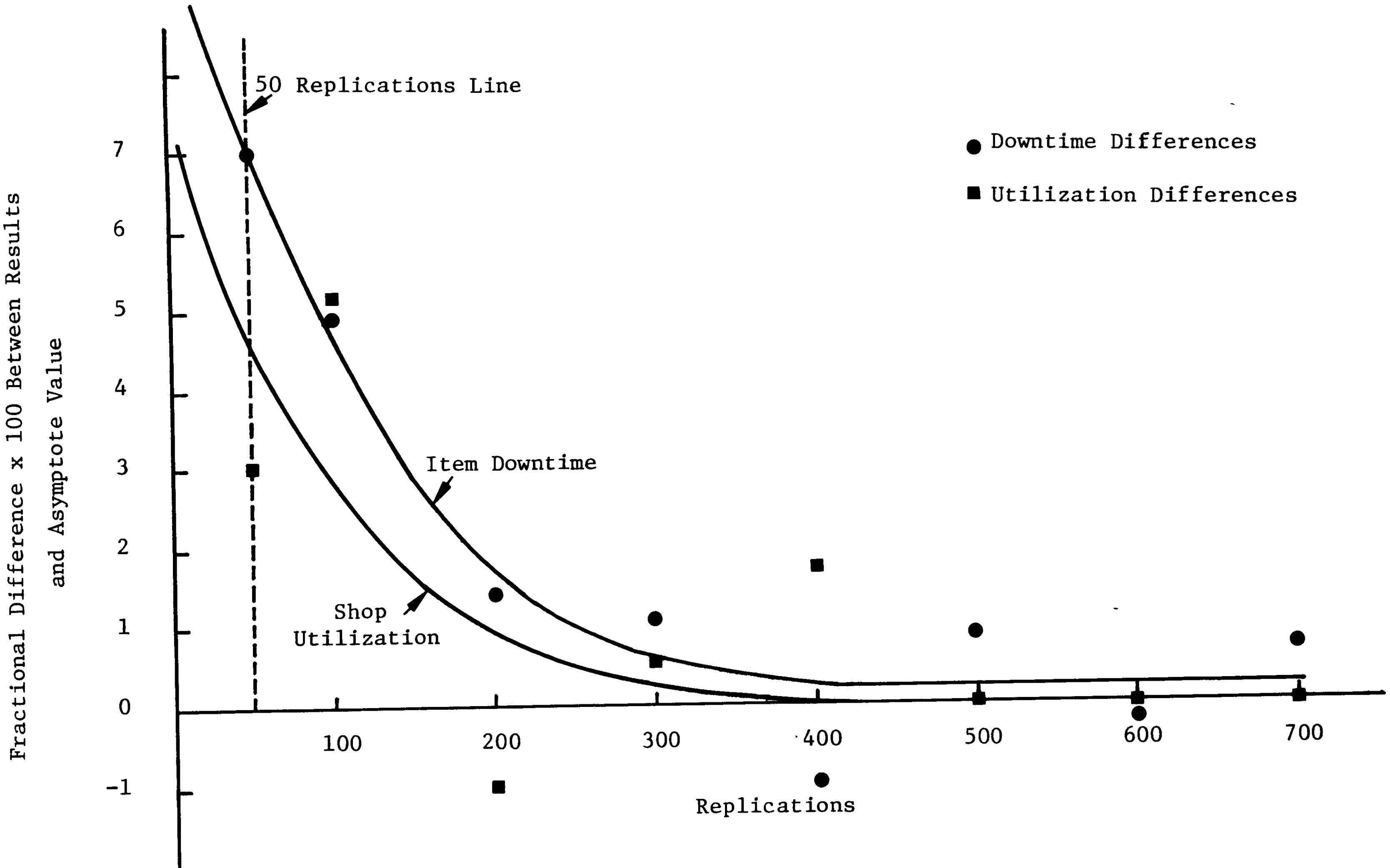

FIGURE 5 - FRACTIONAL DIFFERENCES vs. REPLICATIONS FOR THE MOTOR TRANSPORT CLASS RUN FOR 10 DAYS

The slopes at a greater number of replications are much less steep, and therefore, correspondingly smaller decreases in fractional differences are obtained. However, even 200 to 300 replications represented an unacceptably long running time and a value of 50 replications was chosen as a more practical number. The run with 50 replications produced fractional differences of 0.070 and 0.046 from the asymptotic value in downtime and utilization, respectively. These differences were considered not excessive since the accuracy of the input data was only of the order of 10%.

7.2.2 Theoretical Procedure

The empirical procedure described in the previous section indicates that acceptable results for the Motor Transport Commodity Class can be obtained with 50 replications. However, the number of replications required will vary with each commodity class, because each class has different end item populations and MTBF's. Because it would be tedious to go through this procedure for each run of each commodity class, an equation was derived which calculates the required number of replications for any commodity class and provides a means for automatically terminating the simulation after a given accuracy is reached.

In accordance with the Central Limit Theorem, the distribution of the sample mean $\bar{x}$ of a random variable x_i will approach the normal distribution if the original random variable has any one of a large class of distributions.

Thus let n = number of simulated missions

$x_1 \ldots x_n$, random observations of a given output parameter for each replication

$\bar{x}$, mean value of n random values; i.e.,

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad (14)$$

; $\bar{x}$ represents final output value of parameter (e.g., downtime) for a run consisting of n replications.

The estimated standard deviation of the population based on n observations is

$$\hat{\sigma}(x) = \left[\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1} \right]^{1/2} \tag{15}$$

and the standard deviation of $\bar{x}$ is then

$$\hat{\sigma}(\bar{x}) = \frac{\hat{\sigma}(x)}{\sqrt{n}} \tag{16}$$

Using a standard result based on the normal distribution of $\bar{x}$, the interval $[\bar{x} - 2\hat{\sigma}(\bar{x}), \bar{x} + 2\hat{\sigma}(\bar{x})]$ may be expected to contain the true value of the output (of which $\bar{x}$ is an estimate) with a probability of approximately 0.95.

Therefore an accuracy measure, $A(\bar{x})$, may be defined as the length of the above confidence interval expressed as a fraction of $\bar{x}$.

$$A(\bar{x}) = \frac{4\hat{\sigma}(\bar{x})}{\bar{x}} = \frac{4\hat{\sigma}(x)/\sqrt{n}}{\bar{x}} \tag{17}$$

As the results become more accurate, $A(\bar{x})$ gets smaller. A value of 0.1 is assumed for $A(\bar{x})$. Thus a $4\hat{\sigma}(\bar{x})$ interval of width 10% of $\bar{x}$ will contain the output parameter with a probability of approximately 0.95. Missions are simulated in the model until

$$A(\bar{x}) \leq 0.1$$

Substituting 0.1 for $A(\bar{x})$ provides the following test:

$$0.1 \geq \frac{4\hat{\sigma}(x)/\sqrt{n}}{\bar{x}} \tag{18}$$

After each simulated mission (the nth mission) $\hat{\sigma}(x)$ and $\bar{x}$ are computed and substituted into Equation (18). When the term on the right is less than or equal to 0.1, the desired accuracy has been obtained and the run terminates.

7.3 SPECIFIC MODEL ASSUMPTIONS

Although the model was constructed as accurately as possible, simplifying assumptions were required wherever accuracy requirements imposed an unrealistic burden on the programming of the model. The following assumptions were made to simplify analysis and programming and did not unreasonably affect the accuracy of the results:

(a) no battle damage inflicted

(b) no interaction between maintenance and other subsystems within SMLS

(c) unlimited transportation available

(d) item failures and transportation requirements occur uniformly at all hours of the day

(e) all maintenance at unit, by CT, and at seabase is available 24 hours a day

(f) use of the exponential distribution in generating failures and repair.

Since estimates of battle damage under the SMLS concept were not readily available, none were incorporated. This assumption is not unrealistic, since the SMLS concept postulates conflict of only low- and mid-intensities and therefore battle damage would be minimal. Furthermore, at the level of accuracy used, additional low failure rates due to battle damage added to present failure rates would have little effect.

Assumption (b), that the operations and requirements of the other subsystems in SMLS do not interact with the maintenance subsystem, means that other subsystems (e.g., supply) do not affect the calculation of the maintenance subsystem requirements and performance. In reality, the supply subsystem would most logically interact to some extent with the maintenance system. Since the Marine Corps characteristically does not keep complete inventories of repair parts in the field, delays of 10-30 days are common in supplying repair parts to the maintenance subsystem. The model assumes that all repair parts required during the mission are on hand at the seabase but if realistic delays were considered, calculated downtimes would be greater and availabilities lower. Since the simulation model is used primarily in comparing performance of different configurations, this assumption will have little effect, providing it is considered in the baseline and all other cases.

Assumption (c), that transportation is always available when required, was made for simplification. However, transportation times which were generated by the SMLS Simulation Model[1], did incorporate average waits for transportation.

Assumption (d) was made to simplify the model. All items can fail around the clock, but most items do not operate a full 24 hours a day. Total hours of operation per day is specified in the input.

Assumption (e) implies that the seabase, units, and CT's operate on a 24-hour day. However, utilization figures for CT's, units, and the seabase maintenance can be interpreted as less than a 24-hour day. See Section 6.1.

Assumption (f) was made because exponential failure distributions have been shown to apply to items of the type considered. They are more easily manipulated, and more of the required input data exist, than for other distributions.

SECTION 8

PRESENTATION OF RESULTS

In the maintenance model, MTBF's and MTTR's form the basis for the entire maintenance cycle. The limited accuracy of these data prevents absolute reliance on the results of the model. Therefore, a baseline maintenance configuration was generated and used to compare the various alternate maintenance configurations investigated by the model.

8.1 BASELINE CONFIGURATION

The 34th MAU was used as the baseline configuration. The maintenance capability of each unit is listed in Table 3. The highest maintenance capability provided is 3rd-echelon and no ORF was deployed with the units. The 34th MAU was simulated in the model and item availability, shop utilization, and cost figures were computed. These baseline values were compared to the corresponding values in each alternate maintenance configuration run in the model.

Because of the scarcity of input data, the availabilities as computed in the model will not necessarily correspond to those of the operational systems. However, it is assumed that the differences between the availabilities of simulated maintenance systems (as computed in the model) will be representative of the differences in availability of the same systems if they were tested in the field. All availabilities will be compared with respect to the baseline 34th MAU configuration.

8.2 COMPARISON OF RESULTS

A number of alternative maintenance systems were configured for comparison of maintenance policies. These configurations were designed to indicate the difference between maintenance under SMLS and under the conventional approach. These configurations were run for mission lengths of 10 and 90 days. The 10-day mission represents mid-intensity combat operation; the 90-day mission represents a crisis-control/counter-insurgency operation. From the maintenance point of view, the significant mission specifications were mission length, table of equipment (T/E) (i.e., end items), and corresponding usage factors. Different T/E's were developed for the 10-day and 90-day missions.

The results of the examination of several maintenance configurations are listed in Table 7. Configurations 1 through 6 were run for the 10-day mission. Configuration 1 represents the baseline 34th MAU. Second-echelon maintenance is performed at the units, with the LSU supplying centralized 3rd-echelon and overflow (see Section 2.3) 2nd-echelon maintenance. An ORF was not utilized in this configuration. Configuration (2) uses an ORF but is otherwise the same as (1). Configuration (3) represents the same maintenance capability as (2) but adds a 4th-echelon capability to the LSU. Configuration (4) represents the same maintenance capability at the unit as configuration (3) but now overflow 2nd-echelon, and 3rd- and 4th-echelon maintenance are performed at the seabase; i.e., the LSU is now effectively in the seabase. In configuration (5), all maintenance up to 3rd-echelon is done both at the seabase and by CT's ashore; there is no unit maintenance. Configuration (6) is the same as (5) with 4th-echelon maintenance capability added; i.e., 2nd-, 3rd-, and 4th-echelon repair is done at the seabase with some 2nd- and 3rd-echelon work done ashore by CT's.

Configurations (7) through (11) were run for the 90-day mission, but the longer running times necessitated a less extensive analysis with fewer computer runs. Configuration (7) represents the baseline for the 90-day mission. The other configurations are the same as those for the 10-day mission.

8.3 ANALYSIS OF RESULTS

Figure 6 represents normalized availability* plotted against the number of personnel required to obtain that availability. These results indicate that availability varies little for the three 10-day configurations and shows no decisive advantage to SMLS maintenance over a 10-day period. There is a much larger variation in availability for the 90-day mission. Configuration (8) represents a 9% increase in availability and configuration (10) a 25% increase in availability over (baseline) configuration (7). It is evident that in the 90-day mission SMLS displays a definite advantage not shown in the 10-day mission. This improvement is attributable to the

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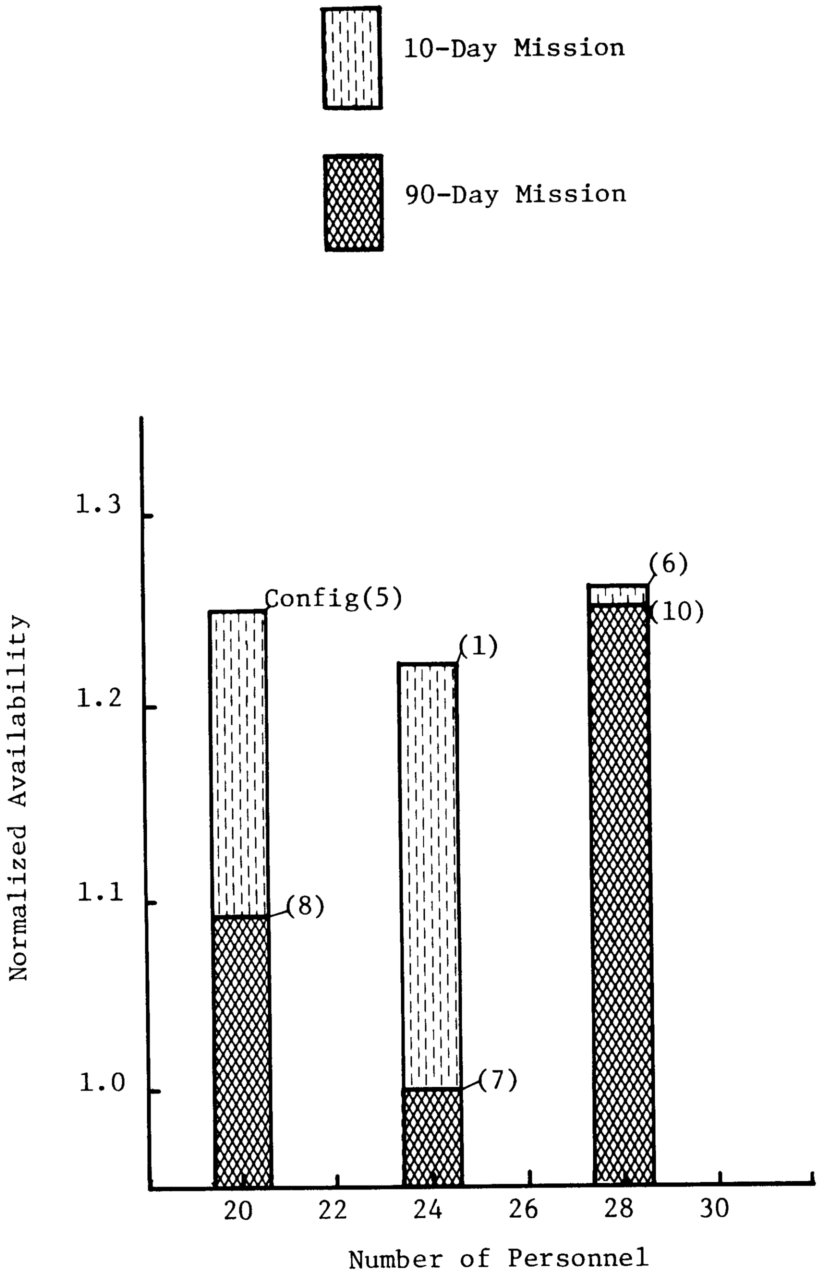
* Normalized availability is the computed availability divided by the availability of the baseline 34th MAU for the 90-day mission, i.e., configuration (7). Cases (2), (3), (4), (9), and (11) are not displayed, but may be compared as desired.

TABLE 7 - RESULTS OF VARIOUS MAINTENANCE CONFIGURATIONS RUN FOR 10- AND 90- DAY MISSIONS

CONFIGURATION NUMBER	CONFIGURATION DESCRIPTION	NUMBER OF MAINTENANCE PERSONNEL REQUIRED	NUMBER OF ORF ITEMS	NUMBER OF TOOL SETS AND KITS	DOWN-TIME (HRS)	AVAILABILITY	NORMALIZED AVAILABILITY $\frac{\text{Availability}}{\text{Availability}_{\text{config. 7}}}$
			10-DAY MISSION				
1	2nd-echelon at unit (34th MAU) Overflow 2nd and 3rd at LSU	24	0	207	3743	0.961	1.22
2	Same as 1., with ORF	24	48	207	1463	0.985	1.25
3	2nd-echelon at unit Overflow 2nd, 3rd, and 4th at LSU	32	48	258	940	0.990	1.03
4	2nd-echelon at unit Overflow 2nd, 3rd and 4th at seabase	32	48	258	1141	0.988	1.03
5	2nd and 3rd-echelons at seabase or with CT's	20	48	104	1530	0.984	1.25
6	2nd, 3rd and 4th-echelon at seabase; also 2nd and 3rd with CT's	28	48	153	839	0.991	1.26
			90-DAY MISSION				
7	Same as 1	24	0	207	134385	0.785	1.00
8	Same as 5	20	48	104	88866	0.857	1.09
9	Same as 6., but no ORF	28	0	153	34311	0.945	1.20
10	Same as 6	28	48	153	10350	0.983	1.75
11	Same as 6., but with 20 ORF items	28	20	153	17759	0.971	1.24

NOTE: Those 10- and 90-day configurations above which have the same description have different Tables of Equipment T/E. Generally, each different mission will require a different T/E.



. FIGURE 6 - AVAILABILITY vs. PERSONNEL
FOR 10- AND 90-DAY MISSIONS

large number of items that can be repaired due to the existence of the ORF. Maintenance configurations (6) and (10) with 2nd-, 3rd-, and 4th-echelon repair at the seabase show almost no degradation in availability from 10- to 90-day operations. The baseline configurations (1) and (7) show a 22% difference in availability because of the large number of items requiring 4th-echelon maintenance that cannot be repaired during the 90-day mission.

From a cost-effectiveness point of view, configurations (5) and (8) with 2nd- and 3rd-echelon maintenance at the seabase are the best. They require fewer personnel than the baseline configuration and give greater availability. Comparison of configurations (8) and (10) (i.e., the addition of 4th-echelon maintenance) for the 90-day mission shows a 16% increase in availability at a cost of eight more (or 33%) personnel.

Figure 7 shows the normalized availability plotted against the number of tool sets and kits for the same configurations examined in Figure 6. For the 90-day mission both SMLS configurations (8) and (10) required fewer tool sets and kits (TSK) than the baseline configuration (7) and resulted in higher availabilities. This decrease in TSK requirements was due to the centralization of maintenance at the seabase.

Figure 8 shows number of personnel required plotted against TSK for the 10-day scenario. Configurations (6) and (3) represent a 2nd-, 3rd-, and 4th-echelon capability. Configurations (1) and (5) represent only a 2nd- and 3rd-echelon capability. For both SMLS cases (configurations (5) and (6)), fewer TSK and personnel are required than with the conventional cases (configurations (1) and (3)) to give corresponding maintenance capabilities. The addition of 4th-echelon maintenance to both configurations has the same effect; i.e., an increased requirement for 50 TSK and eight persons, since 4th-echelon maintenance is centralized in both SMLS and the conventional method.

Figure 9 shows the availability for three SMLS configurations run for 90 days with changes in the number of ORF items. The initial deployment of ORF items was 48 (configuration (10)). Configuration (9) was run with no ORF items. By selectively adding 20 ORF items configuration (11) is obtained. The availability in configuration (11) is only 1% less than in configuration (10), although configuration (11) has 28 fewer ORF items. Thus cost effectiveness dictates the use of configuration (11), where the

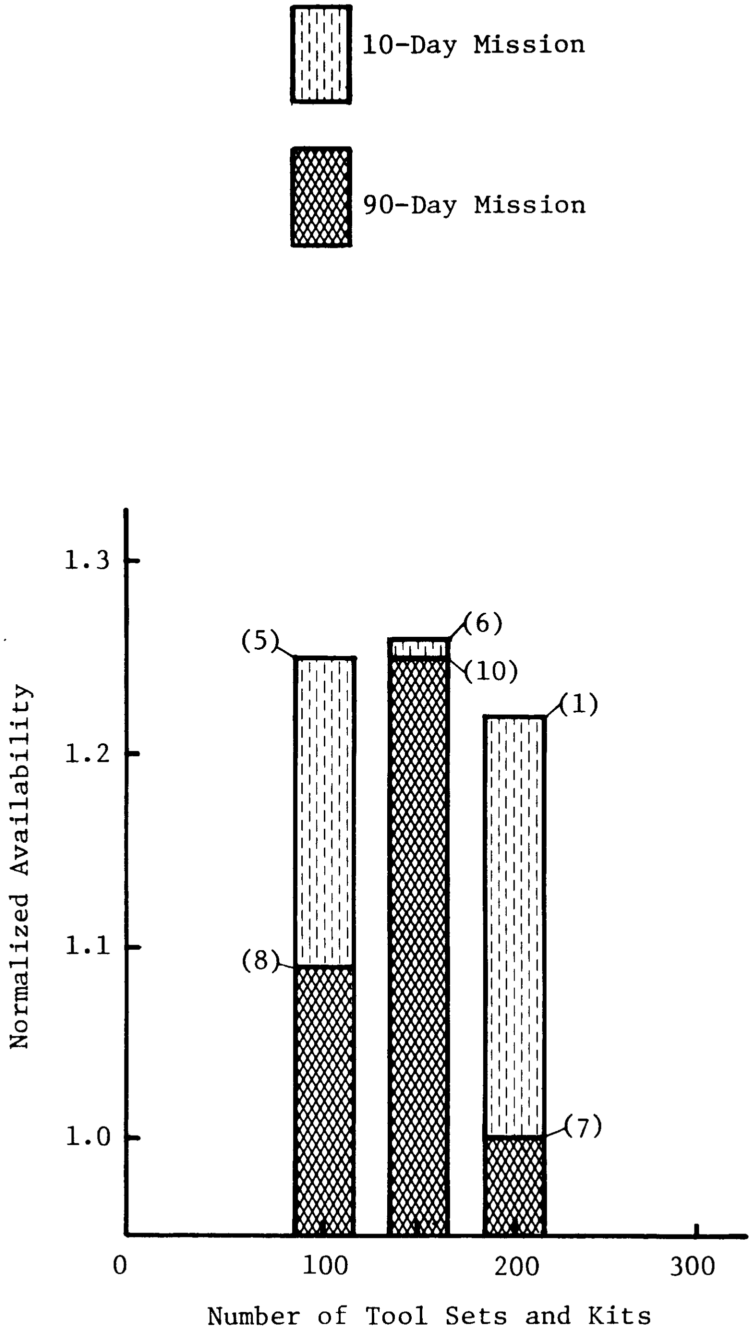


FIGURE 7 - AVAILABILITY vs. TOOL SETS AND KITS FOR 10- AND 90-DAY MISSIONS

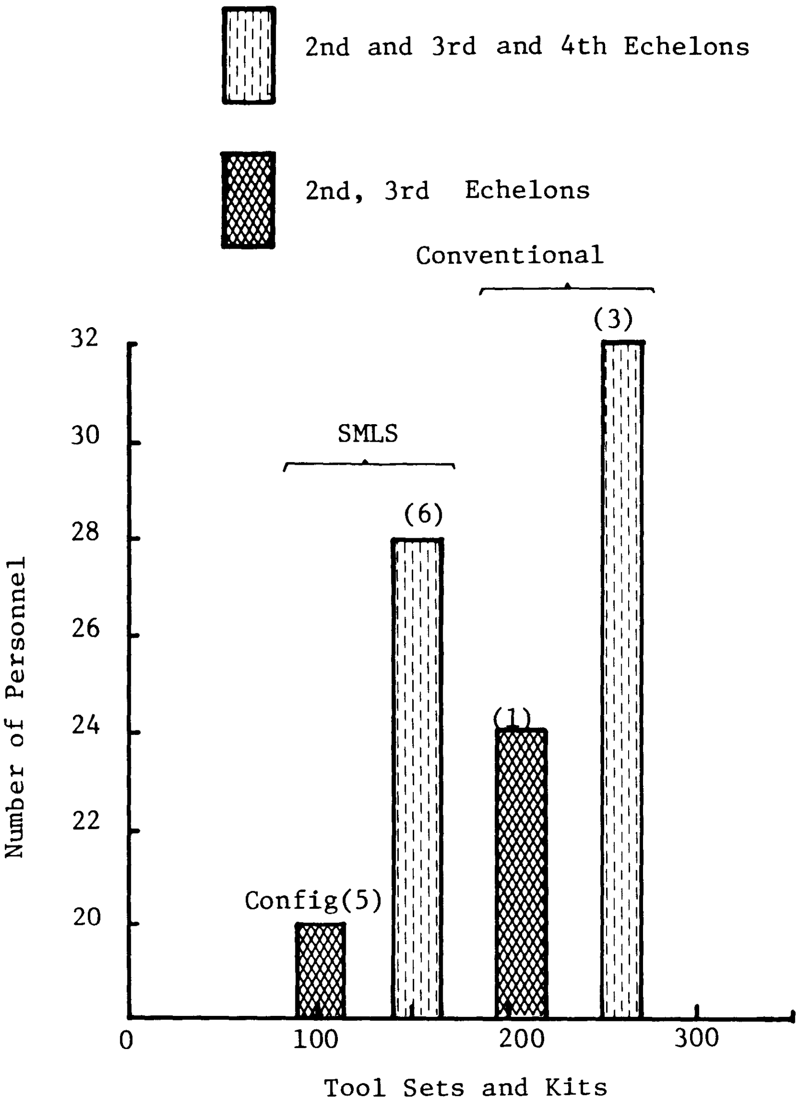


FIGURE 8 - PERSONNEL vs. TOOL SETS AND KITS
10-DAY MISSION

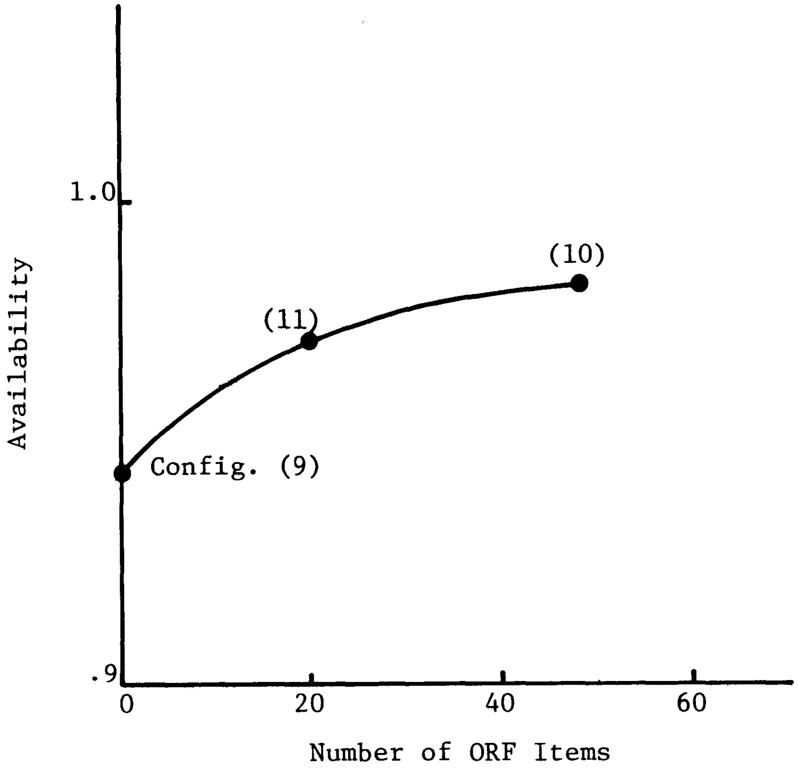


FIGURE 9 - AVAILABILITY vs. ORF LEVEL
90-DAY MISSION

highest availability is obtained with a minimum number of ORF items.

8.4 CRISIS CONTROL MISSION

A number of computer runs were made to observe changes in availability as a function of elapsed time throughout a mission. The crisis-control mission was used because its longer duration was appropriate for this analysis. Examination of values at intermediate times gave a curve of the availability as a function of time. Four configurations were examined:

(1) 34th MAU, 2nd-echelon repair at units, 3rd-echelon repair at LSU, no ORF items

(2) 34th MAU, 2nd-echelon repair at units, 3rd-echelon repair at LSU, 48 ORF items

(3) SMLS, 2nd-, 3rd-, 4th-echelon repair at seabase or with CT's, no ORF items

(4) SMLS, 2nd-, 3rd-, 4th-echelon repair at seabase or with CT's, 48 ORF items

These configurations were run for 10-, 70- and 90-day durations. The downtimes for each commodity class and the resulting availabilities are given in Table 8 and plotted in Figure 10.

Configurations (1) and (2) represent the baseline MAU with and without an ORF. Configurations (3) and (4) represent SMLS utilizing CT's, with and without an ORF.

At 10 days, the difference in availability between configurations (1) and (3) is 2% and between configurations (2) and (4) is 0.3%. Therefore at 10 days the difference in availabilities between SMLS and the 34th MAU is not significant. Furthermore the use of ORF items does not greatly affect the availability.

Availability does not decrease materially under SMLS configurations (3) and (4) until 40 days, at which point, the availability degrades slowly up to 90 days. For configuration (2), 34th MAU with an ORF, the availability slowly degrades linearly, until 90 days. Finally for configuration (1), 34th MAU without an ORF, the availability decreases somewhat more steeply with some increase in slope at later times. This behavior indicates the effect of the ORF on the 34th MAU configuration.

At 90 days, the difference in availability between configurations (1)

TABLE 8 - AVAILABILITY IN CRISES CONTROL MISSION RUN FOR 10, 70 AND 90 DAYS

COMMODITY CLASS	48 ORF ITEMS			NO ORF ITEMS		
	10 DAYS	70 DAYS	90 DAYS	10 DAYS	70 DAYS	90 DAYS
		DOWNTIME (HR)			DOWNTIME (HR)	
		(4)			(3)	
SMLS						
Comm/Elec	163	1360	2732	571	8300	17765
Eng	43	734	1392	119	1392	2772
Mot Tr	140	2468	5752	427	5783	12450
Ord	19	173	473	80	1113	2185
Total DT	365	4735	10349	1197	16588	35172
Availability	0.995	0.989	0.983	0.983	0.960	0.944
		(2)			(1)	
34th MAU						
Comm/Elec	156	13306	35863	1197	32984	68240
Eng	85	3165	7074	212	4738	8932
Mot Tr	320	18186	39151	882	22930	45925
Ord	18	2226	6929	174	5111	11288
Total DT	579	36883	89017	2465	65763	134385
Availability	0.992	0.911	0.857	0.964	0.842	0.785

④ **SMLS** - 2nd, 3rd, and 4th echelons at the seabase, CT, 48 ORF items

③ SMLS - Same as above but with no ORF items

② 34th MAU-2nd echelon at unit, 3rd echelon at LSU, 48 ORF items

① 34th MAU-Same as above but with no ORF items

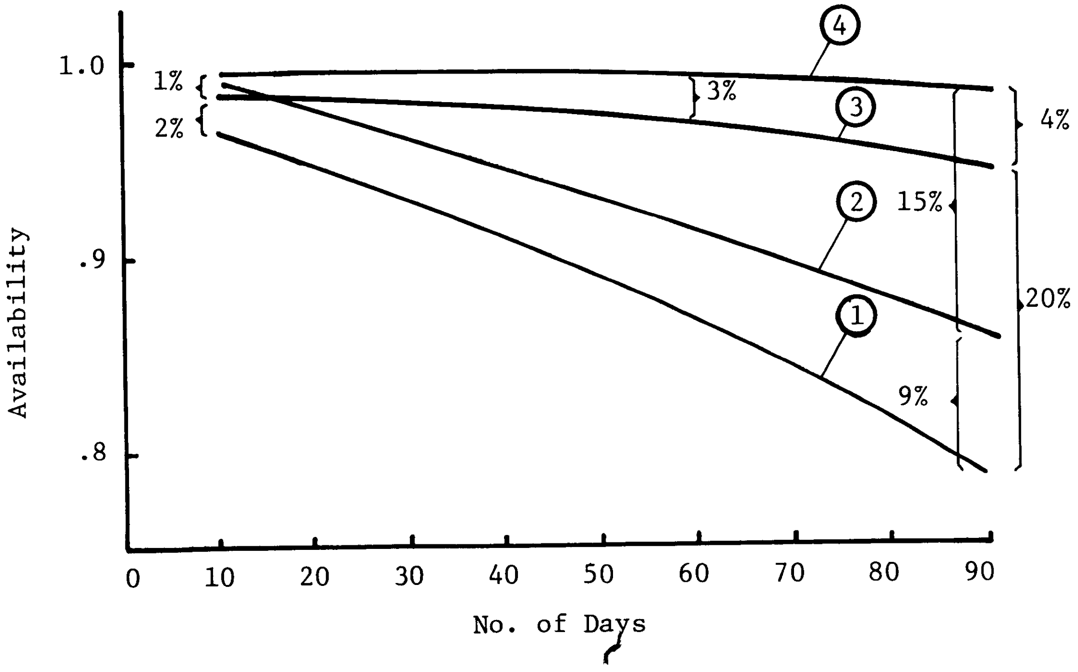


FIGURE 10 - AVAILABILITY AS A FUNCTION OF MISSION DURATION

and (3) is 20% and between configurations (2) and (4) is 15%. Therefore for longer-term operations, the increase in availability under SMLS compared with the 34th MAU is substantial. The use of an ORF in the SMLS configuration creates a 4% increase in availability. Between 0 and 90 days availability under SMLS configurations (3) and (4) decreases an average of 2.7% while under 34th MAU configurations (1) and (2) it decreases an average of 19%.

In summary, as mission length increases

(a) the advantages of SMLS in increasing availability become greater

(b) the advantageous effect of the ORF increases.

8.5 CONCLUSIONS

The following statements are concluded from the results previously presented:

- Ground maintenance support employing shipboard repair facilities is more efficient and effective in most cases than the maintenance support presently employed by the conventional ATU/MAU, i.e., repair ashore.
- Centralization of all maintenance resources (i.e., personnel, equipment, and ORF) in the LSU will enable the ATU/MAU to increase its maintenance capability to limited 4th-echelon repair with fewer resources than when resources are decentralized (unit repair).
- An ORF at the ATU/MAU level will provide increased end item availability by reducing downtime at the unit.

8.6 COMPUTER COSTS

Table 9 shows sample computer times and costs for average runs over 10- and 90-day missions.

For a 9-fold increase in simulated time, i.e., from 10 to 90 days, computer time increased only 3.6 times. The longer the running time, the lower the unit cost. The hourly rate is $368 for a 10-day mission and $246 for a 90-day run.

TABLE 9 - COMPUTER RUNNING TIME AND COST FOR SAMPLE RUN OF MAINTENANCE MODEL

50 Simulated Missions

		10 Day	90 Day
Running Time	Seconds	658	2364
	Minutes	11.0	39.4
$Cost		$67	$160
Hourly Rate		$368/hr	$246/hr

One Hour of Simulated Time
50 Simulated Missions

	10 Day	90 Day
$Cost	28¢	7¢
One Hr Simulated Time Takes On Computer	2.74 sec	1.09 sec

One Hour of Simulated Time
One Simulated Mission

	10 Day	90 Day
$Cost	0.6¢	0.1¢
One Hr Simulated Time Takes On Computer	0.05 sec	0.02 sec

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