THESIS

AN EVALUATION OF
ALLOWANCE DETERMINATION
USING OPERATIONAL AVAILABILITY
by
Patrick Joseph O'Reilly

June 1982

Thesis Advisor: F. R. Richards

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An Evaluation of Allowance Determination Using Operational Availability

Patrick Joseph O'Reilly

Naval Postgraduate School
Monterey, California 93940

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An Evaluation of Allowance Determination Using Operational Availability

by

Patrick J. O'Reilly
Lieutenant Commander, United States Navy
B.B.A., Lamar University, 1969

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT
from the
NAVAL POSTGRADUATE SCHOOL
June 1982
ABSTRACT

Shipboard repair part allowances are presently computed using the Fleet Logistics Support Improvement Program which only considers individual part failure rate data and shipboard population. Two alternate allowance determination models are evaluated which consider other logistics factors when computing allowances. One model maximizes repair part availability using marginal analysis techniques and the other model optimizes system availability. The effectiveness of the three different models are compared for four different systems using the NAUSEA TIGER simulation program. The comparisons show that large improvements in system measures of effectiveness can be achieved using the alternative model which optimizes system availability without any increase in total investment costs for allowances. The alternative marginal analysis model did not produce consistently better results over all system configurations than did the FLSIP model.
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The United States Navy presently determines repair part allowance quantities for most shipboard applications using procedures established under the Fleet Logistics Support Improvement Program (referred to as the FLSIP model). The FLSIP model was designed before the development of highly sophisticated and powerful third and fourth generation computer hardware and software systems. As a result, in its allowance computations, the FLSIP model considers only individual parts usage data and the total population of each part aboard the ship for which allowances are being computed. FLSIP was also designed to support systems which were much less complex and technologically advanced than those being supported in the Navy of the 1980s and 1990s.

To adjust to changes in technology, improved methods for determining shipboard allowance quantities for repair parts must be developed. To the extent that these improved methods can be supported (by computer technology, data collection procedures, etc.) they should include consideration of as many of the other factors in the logistics environment as possible. This would include system configuration, maintenance policy, operational scenario, supply response times, replacement times, component repair times, spares sharing, and the time horizon mission profile. Due to the escalating costs of repair parts, the increased emphasis on cost efficient management in the military and the likelihood of increasingly restrictive cost constraints on inventory levels in the military, these new allocation methods should attempt to optimize with respect to system availability for any fixed cost in inventory investment.
This paper evaluates two shipboard allowance determination models as alternatives to the FLSIP model. A relatively simple marginal analysis model is evaluated which considers the marginal increase in repair part availability to be gained per dollar spent when determining what repair parts should be allowed. This model requires unit cost data in addition to the data required for the FLSIP model. A much more complex optimization model which focuses on maximizing system availability is also evaluated. In addition to the data required for the FLSIP model, the availability model considers equipment unit cost, equipment Mean Time To Repair (MTTR), total budget constraint, and system configuration data. These models are discussed in detail in Chapter III.

An amended version of the NAVSEA.TIGER simulation model is used to compare the effectiveness of each of the three allowance determination models under many different scenarios. Chapter II discusses the capabilities and uses of the amended TIGER simulator. A complete printout of the amended TIGER programs and specific instructions for their use are provided in Appendices B and C. An example of running each allowance determination model on the TIGER simulator is provided in Chapter IV. The results of all the comparisons made during this research are provided in Chapter V.
II. NAVSEA TIGER SIMULATION MODEL

A. INTRODUCTION

The TIGER simulation model is a set of programs developed within NAVSEA to evaluate the performance of complex shipboard operating systems using various measures of effectiveness. This model was modified so that it was compatible with the Naval Postgraduate School computer system in September 1980 by Leather [Ref. 1]. However, due to a complete replacement of hardware and partial replacement of software in December 1980, the model had to be further modified to be compatible with the new computer system. All allowance computations and simulations were run on the IBM system 3033 using the programs in Appendix C. Once data inputs were prepared, an allowance computation and simulation of 1000 missions could be run interactively on a computer terminal in two to six seconds of computer time. All modifications are included in the programs provided in Appendix C.

The TIGER simulation model considers the effect of the following system parameters:

- the Mean Time Between Failures (MTBF) of the equipments/components in the system
- the MTTR of the equipments/components in the system
- the interactions between various equipments/components in the system (as reflected in a reliability block diagram of the system)
- the number of spare parts available to support the system
- the operating cycle for the system and the various components of the system
Before running a system, the appropriate data for the above parameters must be input into the TIGER simulator as discussed in Appendix B. Most of the inputs have to be specified exactly, however the TIGER simulator will compute repair part allowances if that is desired. As originally written, the number of repair parts authorized in a system could be specified exactly or a subroutine could be utilized which would compute repair part allowances for the system under FLSIP procedures (which are utilized by the Navy Ships Parts Control Center to actually determine repair part allowances for Navy ships). FLSIP procedures are discussed in detail in Chapter 3, section A. For this research, two additional subroutines were written for the TIGER simulation model so that repair part allowances for a system could also be computed using the Marginal Analysis model discussed in Chapter 3, section B or using the Availability model discussed in Chapter 3, section C. The main program was also modified to accept spare part unit costs and total budget constraints as input parameters for these models.

B. TIGER OPERATION

The TIGER simulator utilizes Monte Carlo random number techniques to estimate part failure times and times to repair based on the assumption that the times between failures for each part are exponentially distributed with parameter MTBF and the repair time for each part is exponentially distributed with parameter MTTR. The operating status of all parts is then observed at all times during the simulation to determine when the system is "up" and when it is "down". The TIGER simulator considers the inter-relationships between the parts (as specified in the reliability block diagram) to determine whether the system is "up" or
"down". When an acceptable combination of parts are operational then the system is considered to be "up". During those periods of time when an acceptable combination of parts are not operational, the system is considered to be "down".

The TIGER simulator measures the effectiveness of a system using the observed "up" and "down" times for that system over a specified number of missions. The length of each mission is included as an input parameter. The number of missions simulated is also specified in the input parameters and must be between 50 and 1000 (in increments of 50). System effectiveness is computed in the following four ways:

1) Estimated reliability is the probability that a system will perform satisfactorily during an entire mission.

\[
\text{REL(EST)} = 1 - \frac{\text{Number of Mission Failures}}{\text{Total Number of Simulated Missions}}
\]

2) Estimated Instant Availability is the probability that the system will be in an "up" condition at a specific point in time.

\[
\text{AVA INSTANT(EST)} = \frac{\text{Number of Missions Up at Time (t)}}{\text{Total Number of Missions Simulated}}
\]

This value is calculated at the beginning and end of each phase sequence. A mission can contain up to six different operating scenarios. These are defined as phase sequences. For example, for simulating shipboard operations: one phase can represent in port periods, another can represent normal steaming operations, and a third can represent battle engagement periods. The ability to replace parts and the amount of time a part must be operational for the equipment to be considered in an "up" status can be varied from one
phase type to another. Details for doing this are discussed in Appendix B under Card Types 7, 10 and 13.

3) Estimated Average Availability is the probability that the system will be in an "up" condition at a random point in time.

\[
\text{AVA AVERAGE(EST)} = \frac{\text{Summation of Uptime for All Missions Simulated}}{\text{Summation of Total Mission Calendar Time for all Missions Simulated}}
\]

4) Estimated readiness is the probability that the system will be in an "up" condition at a random point in time assuming that the system stays down for the remainder of each mission after its first failure in that mission.

\[
\text{RED (EST)} = \frac{\text{Summation of Uptime for all Missions Simulated (through the first failure)}}{\text{Summation of Total Mission Calendar Time for all Missions Simulated}}
\]

Estimated instant availability and estimated average availability were used to evaluate the three allowance determination models in this research.

C. PECULIARITIES OF USE IN THIS THESIS

Since the objective of this research was to measure the relative effectiveness of three different repair part allowance determination policies, many of the parameters in the TIGER simulator which could have been varied were not. The following input parameters were held constant throughout this research.
1. Timeline phases. Scenarios can be specified where reliability block diagrams change during different phases of the mission timeframe being simulated. For the purposes of this study, only one phase was used for all simulations which lasted the entire length of each mission.

2. Mean Time To Repair. MTTR was established as one hour for all equipments.

3. Allowable Downtime. Equipments can be allowed to fail for a certain length of time without causing the system to fail regardless of their position in the reliability block diagram by having specified allowable downtimes. The allowable downtimes for all equipments used in this research were set to zero.

4. Three Levels of Repair Parts Support. Additional support from repair parts located at an intermediate level supply activity (ie. a destroyer tender) and at a depot level supply activity (ie. a Naval Supply Center) can be simulated. However, since the objective of this research was to evaluate the effectiveness of shipboard allowances, it was assumed that no support could be obtained from intermediate or depot level activities during the 90 day mission involved.

D. TIGER OUTPUT

The TIGER simulator produces both standard and optional outputs. The various options are discussed in Appendix B under the Printout Option Card. The optional output used for this research was the management summary printout. It first displays most of the user's input, the allowance determination model used to compute repair part allowances (if one was used), and the number of repair parts being used.
The TIGER simulator then prints a message every time the system goes down indicating which components are down and when they will come back up. Since this portion of the output was voluminous and not useful for analysis during this research, it was suppressed.

Next the TIGER simulator prints the cumulative measures of effectiveness for the system after each group of 50 missions has been simulated. Since this portion of the output was voluminous and not useful until all simulations were completed, it was suppressed until the last mission simulation was completed.

The TIGER simulator then produces tables which summarize data about specific equipment failures, the number of repair parts used, and critical equipments.

Examples of the various outputs produced by the TIGER programs are provided in Appendix D. A detailed explanation of these outputs is provided in Reference 4.
III. ALLOWANCE DETERMINATION POLICIES

A. FLEET LOGISTICS SUPPORT IMPROVEMENT PROGRAM (FLSIP) CONCEPT

The FLSIP concept is presently used by the Ship's Parts Control Center (SPCC) to determine repair part allowances for most shipboard applications. It requires two inputs. First, the average usage rate (on an annual basis) must be known for each repair part. This is denoted as the Best Replacement Factor (BRF). Since most initial usage data available to the Navy is in the form of MTBF data, it must be converted for use in the FLSIP model. Since MTBF is measured in hour units and BRF is measured in annual units, the hourly MTBF data must be divided into 8760 (the number of hours in a 365 day year) to get a BRF figure. The formula for conversion is:

\[ BRF = \frac{8760}{MTBF} \]

Second, the total number of times each repair part is installed in the various equipments aboard the ship must be known. This is known as the shipboard population (POP). These two numbers are then multiplied to get the expected number of failures for each part aboard that ship in a one year period of time. This is taken as the mean for each part.

\[ \text{mean annual demand} = BRF \times POP \]
Ignoring minimum replacement units, technical overrides, etc., the shipboard allowances for each repair part are then determined as follows.

1. If the mean annual demand for a part is greater than or equal to 1.0, the shipboard allowances will be based on anticipated demand. The allowance will be set equal to the minimum number of spares that will provide at least a 90% probability that actual demand for the part during a 90 day period will not exceed the allowance quantity (assuming a Poisson distribution of demand).

2. If the mean annual demand for a repair part is greater than or equal to .25 but less than 1.0, the shipboard allowance will be set to one. These allowances are insurance items. (.25 is the insurance item cut point - also known as the FLSIP cut point.) Several years ago, as a result of funding pressures, this cut point was adjusted up from .15 to reduce the number of insurance items allowed. It can be adjusted up or down to provide more or less insurance protection for certain types of ships but the main emphasis in this paper will be with the .25 level.

3. If the mean annual demand for a part is less than .25 (or other specified cut point), no shipboard allowance will be established.

Funding constraints for shipboard repair parts can be accommodated by increasing the FLSIP cut point as discussed above. However, since almost all the parts used in the systems being evaluated for this paper were assumed to be
high failure rate parts, a change of the FLSIP cut point has little effect on the value of parts required to support those systems. This is due to the fact that most of the means were greater than 1.0 so the allowances were based on demand and adequate repair parts were allowed to meet the 90% issue criteria regardless of the insurance item (FLSIP) cut point. Even if the cut point were changed from .25 (ie. one demand every 4 years) to 1.0 (ie. one demand every year), the FLSIP computed allowances would exceed the budget constraints desired in most cases considered in this thesis.

Note: A study conducted by the Center For Naval Analysis [Ref. 2] has recommended the following changes to the FLSIP model:

a. Items supporting equipments essential to a primary mission of the ship would be identified and the insurance item stockage threshold for these items would be lowered to .10 (one unit demanded in 10 years), and

b. High demand insurance items would be stocked in insurance quantities of two each instead of one each as is now done.

This revised FLSIP model was not considered in this research.

Since changing the FLSIP cut point was not considered to be an effective way to constrain expenditures for the FLSIP model for the systems analyzed for this paper, the availability objective of the model was varied instead. By varying the availability objective, a budget constraint could effectively be introduced into the FLSIP model. To do
this, the probability of not being out of stock in the FLSIP model was allowed to decrease until a low enough probability was reached to allow a set of FLSIP allowances to be computed within a specified budget constraint. The specified availability started at 90% and was decreased in increments of 5%. At each increment, FLSIP allowances were determined using the decreased probability and the cost of the repair parts was computed. If the total cost of repair parts was less than the funding constraint specified, then the FLSIP repair parts list was used. If the cost exceeded the funding constraint, that repair parts list was discarded and another set of FLSIP allowances were determined using a 5% lower specified availability. This procedure is illustrated on Table I.

Note that some of the different availability levels have the same allowance costs. This is true because they have the same allowance levels. Different availability levels can have the same allowance levels because repair part allowances do not change linearly with availability levels. Since repair parts must change in increments of one, the change in expected availability may decrease substantially by deleting one part. For example, if a part has an MTBF of 1720 hours, the probability of having no demands in a 90 day period is 28%. So protection levels between zero and 28% can be obtained without carrying any spares. If, on the other hand, one spare is carried, a protection level of 64% is obtained. So protection levels between 29% and 64% all require that one spare be carried. For the program written for this research, that means that protection levels of 60%, 55%, 50%, 45%, 40%, 35% and 30% would all require an allowance of one. Not until the required availability level reached 25% would there be a change in the allowance for this part.
The availability objective is varied in the .25 FLSIP model to facilitate the computation of allowances within specified budget constraints. The use of the availability objective for this purpose is demonstrated with the following system.

**TABLE I**

Use of the Availability Objective in the .25 FLSIP Model

<table>
<thead>
<tr>
<th>Part Number</th>
<th>MTBF</th>
<th>POP</th>
<th>ANNUAL DEMAND</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2500</td>
<td>1</td>
<td>5.94</td>
<td>150.00</td>
</tr>
<tr>
<td>2</td>
<td>750</td>
<td>1</td>
<td>11.68</td>
<td>152.00</td>
</tr>
<tr>
<td>3</td>
<td>750</td>
<td>1</td>
<td>11.68</td>
<td>153.00</td>
</tr>
<tr>
<td>4</td>
<td>1500</td>
<td>1</td>
<td>5.94</td>
<td>154.00</td>
</tr>
<tr>
<td>5</td>
<td>750</td>
<td>1</td>
<td>11.68</td>
<td>156.00</td>
</tr>
<tr>
<td>6</td>
<td>7500</td>
<td>1</td>
<td>1.17</td>
<td>155.00</td>
</tr>
<tr>
<td>7</td>
<td>7500</td>
<td>1</td>
<td>3.40</td>
<td>157.00</td>
</tr>
</tbody>
</table>

For this system, unconstrained .25 FLSIP allowances would cost $3058.00 as shown on the 90% availability line below. To determine the allowances when the funding is constrained to 75% of the fully funded costs (ie. 2293.50), the amended TIGER FLSIP procedure is:

1st: Set the high limit for the constrained allowances to 5% higher than the specified limit (the high limit here is $2293.50 x 1.05 = $2408.18). This is done to ensure that optimal combinations just slightly above the specified budget constraint will be considered.

2nd: Compute spares required for various availability objectives (starting at 90% and going down 5% at a time) until a set of spares is found which will be less than the budget limit high as shown below.

<table>
<thead>
<tr>
<th>% AVAIL OBJECT COST</th>
<th>Number of Repair Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Part #1</td>
</tr>
<tr>
<td>90</td>
<td>$3058</td>
</tr>
<tr>
<td>85</td>
<td>3058</td>
</tr>
<tr>
<td>75</td>
<td>2443</td>
</tr>
<tr>
<td>70</td>
<td>2443</td>
</tr>
<tr>
<td>65</td>
<td>2143</td>
</tr>
</tbody>
</table>

Since $2143 is less than $2408, the repair parts computed at the 65% availability objective will be used as the allowances for the 75% funding level.
B. MARGINAL ANALYSIS CONCEPT

One of the deficiencies of the FLSIP model as now used is that it ignores the cost of the spare parts in its computations and in the decision process. The FLSIP model is also very limited in its ability to adjust to funding constraints because this is presently only done by adjusting the insurance cut point. This can result in the inefficient allocation of budget dollars due to variances in the relationships between the unit costs and the reliabilities of the various repair parts. The marginal analysis concept, on the other hand, does consider the cost of the individual items and is designed to accommodate a budget constraint on the total amount of dollars available for spare parts. There are many different possible marginal analysis policies. The one evaluated in this paper selects that combination of parts (for a given set of parts) that will provide the highest total parts availability for a given dollar value constraint. Four inputs are required for this concept. The following three inputs must be known for each part: MTBF, total number of parts in the system, and the unit cost. In addition, a total dollar value constraint for the repair parts allowance must be known. The shipboard repair part allowances are then determined by stepwise adding an additional spare for that item showing the greatest increase in probability of a fill per dollar spent. The incremental improvement in the probability of a fill is the difference

$$\pi(x_i = x) - \pi(x_i = x-1),$$

where $x$ is the number of spares of item $i$ and $x_i$ is the demand for spares of item $i$. This turns out to be
identically equal to the probability of a demand for exactly $x$ spares or $p_i(x) = P(X_i = x)$. The policy is illustrated with a simple example involving only the three parts shown in Figure 3.1.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>MTBF</th>
<th>Pop</th>
<th>Mean 90 Day Demand</th>
<th>Unit Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1720</td>
<td>1</td>
<td>1.26</td>
<td>$200.00</td>
</tr>
<tr>
<td>2</td>
<td>1720</td>
<td>1</td>
<td>1.26</td>
<td>50.00</td>
</tr>
<tr>
<td>3</td>
<td>3000</td>
<td>1</td>
<td>.72</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Figure 3.1 Example System for Marginal Analysis Model

Step 1. First, we want to determine the marginal benefit (in probability of filling demands) of adding a single spare of each item. For our example:

$p_1(1) = .35634142$  $p_2(1) = .35634142$  $p_3(1) = .3518585$

Step 2. Then for each part, we determine the marginal benefit to cost ratios by dividing the values in step 1 by the unit cost of the part. For our example:

$\frac{p_1(1)}{C_1} = .0017817$  $\frac{p_2(1)}{C_2} = .0071268$  $\frac{p_3(1)}{C_3} = .0035186$

The resulting value is the marginal benefit per dollar invested of adding one of each of the parts.

Step 3. The part with the highest ratio calculated in step number 2 is assigned a single spare. For our example,
the part with the highest marginal availability is part number 2.

Step 4. The total cost of all assigned repair parts is then compared to the budget constraint. For our example, the current total cost of assigned repair parts is $50.00 as shown in Figure 3.2. If the constraint has been reached or exceeded, the computations are concluded with the parts allowances assigned to that point. If the budget constraint has not been reached, the model continues on to step 5.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Allowance</th>
<th>Unit Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0-</td>
<td>$200.00</td>
<td>-0-</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>50.00</td>
<td>50.00</td>
</tr>
<tr>
<td>3</td>
<td>-0-</td>
<td>100.00</td>
<td>-0-</td>
</tr>
<tr>
<td><strong>Total Costs</strong></td>
<td></td>
<td></td>
<td><strong>$50.00</strong></td>
</tr>
</tbody>
</table>

Figure 3.2 Total Costs of Allowances Assigned After First Iteration

Step 5. A revised marginal availability is calculated for the part which was assigned an allowance in step 3. One additional spare is now considered for that part and the probability of that many demands in a 90 day period is calculated. For our example, the revised marginal availability for part number 2 is \( p_2(2) = 0.22701228 \). The new marginal benefit to cost rate for this item is then computed by dividing the revised marginal availability of the item by its unit cost. For our example:

\[
\frac{p_2(2)}{C_2} = \frac{0.22701228}{50} = 0.00454024
\]
The model then brings along the information from step 2 for those items not selected for an increase in spares in step 3 and repeats the same type of comparison as was done in step 3. For our example, the benefit to cost rates are now:

\[
\frac{p_1(1)}{C_1} = 0.0017817 \quad \frac{p_2(2)}{C_3} = 0.00454024 \quad \frac{p_3(1)}{C_3} = 0.0035186
\]

The next spare will again be assigned to part number 2 since it still shows the maximum rate.

The above process continues until the specified budget constraint is reached.

C. AVAILABILITY CONCEPT

The availability of equipments and systems afloat are a function of many factors as discussed in Chapter 1. One weakness of both the FLSIP and Marginal Analysis models is that neither of them considers many of those factors. They, in essence, ignore many operational issues which should be considered by a model of this type to be as accurate as possible. Another weakness of both of those models is that the measure of effectiveness for the system is not system related and consequently, one cannot relate resources to readiness (i.e., system availability). Man Won Jee [Ref. 3: ch. 4], developed a mathematical model for computing repair part allowances to support any given system. The model optimizes the instant operational availability of a system for any given budgetary constraint. This is referred to as the Availability model. The Availability model improves upon both the FLSIP and Marginal Analysis models by including several more of the pertinent operational factors. Those factors included in the Availability model which are not considered in either of the other models are the Mean
Time To Repair (replace) a component and a consideration of the interactions between the various components in the system. Like the Marginal Analysis model, the Availability model also considers the unit cost of each repair part and the total budget constraint on the repair parts allowed. In addition, the Availability model improves upon the FLSIP and Marginal Analysis models by relating resource utilization to optimizing system availability which is the measure of effectiveness.

For a single component system, Jee showed that the availability after \( t \) units of time of a component having \( n \) spares is given by

\[
A^n(t) = A^{n-1}(t) + \left( (f \ast g) \ast \cdots \ast f \right)(t)
\]

where \( f(t) \) is the probability density of component lifetimes, \( g(t) \) is the probability density of replacement times, \( F(t) = P(T \leq t) \) and \( (f \ast g) \)
represents the \( k \)-fold convolution of \( f \) and \( g \).

Jee further showed that for the special case in which

\[
f(t) = ((\text{lambda})(t))^{-\lambda(t)}; \text{ and} \]
\[
g(t) = ((\text{nu})(t))^{-\nu(t)};
\]

the marginal contribution that the \( n \)th spare provides to system availability is:
\[ \left( f^{(k)} \right) \ast \left( q^{(k)} \right) \ast \left( \frac{1}{p} \right) (t) = \]

\[ \frac{-1}{\phi} \cdot \frac{k}{k!} \cdot \frac{t}{k} + \sum_{r=1}^{k} (-1)^{r+1} \cdot \frac{(k-r-1)!}{r!} \cdot \frac{t^r}{(k-r)!} \cdot e^{-lt} \]

\[ + (-1)^{k+1} \cdot \phi \cdot \frac{k}{(k+1)!} \cdot \frac{t}{k+1} + \sum_{l=1}^{k+1} \frac{(k+1)!}{l!} \cdot \frac{t^l}{(k+1-l)!} \cdot e^{-lt} \]

where: \( \lambda = \text{lambda}, \ n = \text{nui}, \ 0 = \ln, \ \delta = n-1 = 0, \ \text{and} \]

\[ p_n^k = \frac{n!}{(n-k)!} \cdot \]

The above formula is referred to as the JEE formula throughout this paper. All systems analyzed in this paper were assumed to have parts with exponentially distributed times between failures and replacement times so the JEE formula is used for all calculations. An example of the results of using the JEE formula to determine the contribution to system marginal availability of individual spares is shown in Table II. A maximum of 9 spares for a given part are allowed when using the JEE formula in the amended TIGER model written for this research effort.

Jee then developed a repair parts allocation algorithm that utilizes the JEE formula to optimize the instant operational availability of a system by efficiently allocating the number of spares for each component in a "k" component system [Ref. 3: ch. 6]. The algorithm he developed is basically a dynamic program which is then used to determine the most efficient combination of repair parts for each budget amount.
TABLE II

JEE Formula Computations: An Example

Data for Sample System:

<table>
<thead>
<tr>
<th>Part Number</th>
<th>MTBF</th>
<th>MTTR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1000.0</td>
<td>10.00</td>
</tr>
<tr>
<td>2</td>
<td>3000.0</td>
<td>10.00</td>
</tr>
</tbody>
</table>

Parts 2 and 3 are in parallel. Part 1 is in series with the combination of parts 2 and 3.

The availabilities for each part number for a range from zero to nine repair parts computed by the JEE formula are:

### AVAILABILITY MATRIX FOR SPARE 1 IS:

<table>
<thead>
<tr>
<th>Part</th>
<th>Allow</th>
<th>Cost</th>
<th>Avail</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.115325</td>
</tr>
<tr>
<td>1</td>
<td>150.0</td>
<td>0.0</td>
<td>0.362767</td>
</tr>
<tr>
<td>2</td>
<td>300.0</td>
<td>0.0</td>
<td>0.635161</td>
</tr>
<tr>
<td>3</td>
<td>450.0</td>
<td>0.0</td>
<td>0.826546</td>
</tr>
<tr>
<td>4</td>
<td>600.0</td>
<td>0.0</td>
<td>0.927569</td>
</tr>
<tr>
<td>5</td>
<td>750.0</td>
<td>0.0</td>
<td>0.969831</td>
</tr>
<tr>
<td>6</td>
<td>900.0</td>
<td>0.0</td>
<td>0.984427</td>
</tr>
<tr>
<td>7</td>
<td>1050.0</td>
<td>0.0</td>
<td>0.988738</td>
</tr>
<tr>
<td>8</td>
<td>1200.0</td>
<td>0.0</td>
<td>0.989796</td>
</tr>
<tr>
<td>9</td>
<td>1350.0</td>
<td>0.0</td>
<td>0.990040</td>
</tr>
</tbody>
</table>

### AVAILABILITY MATRIX FOR SPARE 2 IS:

<table>
<thead>
<tr>
<th>Part</th>
<th>Allow</th>
<th>Cost</th>
<th>Avail</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.649209</td>
</tr>
<tr>
<td>1</td>
<td>151.0</td>
<td>0.0</td>
<td>0.928926</td>
</tr>
<tr>
<td>2</td>
<td>302.0</td>
<td>0.0</td>
<td>0.988628</td>
</tr>
<tr>
<td>3</td>
<td>453.0</td>
<td>0.0</td>
<td>0.997044</td>
</tr>
<tr>
<td>4</td>
<td>604.0</td>
<td>0.0</td>
<td>0.997925</td>
</tr>
<tr>
<td>5</td>
<td>755.0</td>
<td>0.0</td>
<td>0.997999</td>
</tr>
<tr>
<td>6</td>
<td>906.0</td>
<td>0.0</td>
<td>0.998004</td>
</tr>
<tr>
<td>7</td>
<td>1057.0</td>
<td>0.0</td>
<td>0.998004</td>
</tr>
<tr>
<td>8</td>
<td>1208.0</td>
<td>0.0</td>
<td>0.998004</td>
</tr>
<tr>
<td>9</td>
<td>1359.0</td>
<td>0.0</td>
<td>0.998004</td>
</tr>
</tbody>
</table>

### AVAILABILITY MATRIX FOR SPARE 3 IS:

<table>
<thead>
<tr>
<th>Part</th>
<th>Allow</th>
<th>Cost</th>
<th>Avail</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.486752</td>
</tr>
<tr>
<td>1</td>
<td>152.0</td>
<td>0.0</td>
<td>0.836753</td>
</tr>
<tr>
<td>2</td>
<td>304.0</td>
<td>0.0</td>
<td>0.961420</td>
</tr>
<tr>
<td>3</td>
<td>456.0</td>
<td>0.0</td>
<td>0.990767</td>
</tr>
<tr>
<td>4</td>
<td>608.0</td>
<td>0.0</td>
<td>0.995877</td>
</tr>
<tr>
<td>5</td>
<td>760.0</td>
<td>0.0</td>
<td>0.996688</td>
</tr>
<tr>
<td>6</td>
<td>912.0</td>
<td>0.0</td>
<td>0.996669</td>
</tr>
<tr>
<td>7</td>
<td>1064.0</td>
<td>0.0</td>
<td>0.996677</td>
</tr>
<tr>
<td>8</td>
<td>1216.0</td>
<td>0.0</td>
<td>0.996667</td>
</tr>
<tr>
<td>9</td>
<td>1368.0</td>
<td>0.0</td>
<td>0.996667</td>
</tr>
</tbody>
</table>
The sample system shown in Table II will be used to illustrate how the JEE algorithm works. Part numbers 2 and 3 will be used as the first two dynamic programming stages in our illustration. The stage returns from the first two stages are simply the results of initially calculating the marginal contributions of repair parts 2 and 3 using the JEE formula as shown in Table II. These stage returns are then assembled into the matrix shown on Table III so that a sequence of maximum returns from the combination of these two stages can be calculated.

The JEE algorithm always starts in the upper left hand corner of the matrix because that is the minimum cost combination for the two stages being considered. This is the first undominated combination on the matrix. The algorithm determines the cost and system availability of using the combination of repair parts specified at that junction in the matrix. The cost is calculated by simply costing out the repair parts specified at that point. The calculation of the resulting system availability depends upon whether the parts are operating in series or in parallel. If the parts are in series, the system availability is:

\[ \text{AVAIL}_{\text{sys}} = \text{AVAIL}_1 \times \text{AVAIL}_2 \]

If the parts are in parallel, the system availability is:

\[ \text{AVAIL}_{\text{sys}} = 1 - (1 - \text{AVAIL}_1) \times (1 - \text{AVAIL}_2) \]

Parts 2 and 3 shown on Table II are in parallel and the results of the above calculations for the first undominated combination in the matrix on Table III are a cost of $0.0 and an availability of .8199. The same calculations are then made for other pertinent blocks in the matrix. For example, the cost of combining three spares for part number
### TABLE III

**JEE Algorithms Matrix**

<table>
<thead>
<tr>
<th>Part Numbers</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>.9289</td>
<td>.9886</td>
<td>.9970</td>
<td>.9979</td>
<td>.9980</td>
<td>.9980</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>.9841</td>
<td>.9988</td>
<td>.9999</td>
<td>.9990</td>
<td>.9999</td>
<td>.9999</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>.9884</td>
<td>.9981</td>
<td>.9995</td>
<td>.9996</td>
<td>.9999</td>
<td>.9999</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>.9993</td>
<td>.9999</td>
<td>.9999</td>
<td>.9999</td>
<td>.9999</td>
<td>.9999</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>.9997</td>
<td>.9997</td>
<td>.9999</td>
<td>.9999</td>
<td>.9999</td>
<td>.9999</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>.9998</td>
<td>.9998</td>
<td>.9999</td>
<td>.9999</td>
<td>.9999</td>
<td>.9999</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>.9998</td>
<td>.9998</td>
<td>.9998</td>
<td>.9998</td>
<td>.9998</td>
<td>.9998</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>.9998</td>
<td>.9998</td>
<td>.9998</td>
<td>.9998</td>
<td>.9998</td>
<td>.9998</td>
<td></td>
</tr>
</tbody>
</table>

* The top and side rows in the matrix show the number of spares, the total of their unit costs and availability contribution of each of the parts indicated. The numbers within the matrix show the total costs and resulting availabilities from combining the numbers of spares indicated.
2 with three spares for part number three is $909 and the resulting availability for this same combination is .9999. The calculations do not have to be made for all combinations as discussed in detail by Jee [Ref. 3: ch. 6].

Next, the JEE algorithm finds the combination in the matrix which has a combined cost less than any other combination with a system availability larger than that of the previous undominated combination. That combination is the next optimal combination in the matrix. This process is repeated until all undominated combinations on the matrix have been identified (a maximum of 99 undominated combinations can be processed using the amended TIGER model written for this research effort). The first 8 undominated combinations are indicated on Table III. The optimal repair parts allocation at any dollar level can be identified by simply following the arrows on the matrix until the specified dollar level is found. For example, on Table III, a combination of three spares for part #2 and zero spares for part #3 would be optimal for budget levels between $453 and $603 while a combination of four spares for part #2 and zero spares for part #3 would be optimal for a budget level of $604.

The undominated combinations from the matrix in Table III are the returns from stage 3. These returns are then combined with the cost and availability data for the part (or combination of parts) in the next stage of the system. In Table IV, the undominated combinations from Table III are combined with the costs and availabilities for part 3 from Table II. As discussed on Table II, these parts are assumed to be in series. The resulting first eight undominated combinations are shown on Table IV. As can be observed from Table IV, a combination of 4 spares for part #1, 1 spare for part #2, and 0 spares for part #3 is optimal for budget levels between $751 and $900, etc.
### TABLE IV

**JEE Algorithm Matrix** *

<table>
<thead>
<tr>
<th>Part Numbers</th>
<th>0.00</th>
<th>1.00</th>
<th>2.00</th>
<th>3.00</th>
<th>4.00</th>
<th>5.10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>0.11</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>2.00</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>3.00</td>
<td>1.11</td>
<td>1.11</td>
<td>1.11</td>
<td>1.11</td>
<td>1.11</td>
<td>1.11</td>
</tr>
<tr>
<td>4.00</td>
<td>1.14</td>
<td>1.14</td>
<td>1.14</td>
<td>1.14</td>
<td>1.14</td>
<td>1.14</td>
</tr>
<tr>
<td>5.00</td>
<td>1.15</td>
<td>1.15</td>
<td>1.15</td>
<td>1.15</td>
<td>1.15</td>
<td>1.15</td>
</tr>
<tr>
<td>6.00</td>
<td>1.16</td>
<td>1.16</td>
<td>1.16</td>
<td>1.16</td>
<td>1.16</td>
<td>1.16</td>
</tr>
<tr>
<td>7.00</td>
<td>1.17</td>
<td>1.17</td>
<td>1.17</td>
<td>1.17</td>
<td>1.17</td>
<td>1.17</td>
</tr>
</tbody>
</table>

*The top and side rows in the matrix show the number of spares, the total of their unit costs and the availability contribution of each of the parts indicated. The numbers within the matrix show the total costs and resulting availabilities from combining the numbers of spares indicated.*

This combining of matrices is continued until all the parts in the system are included in one of the two axes of the final matrix. Then the optimal combination of repair parts can be identified for any dollar level by looking at the undominated allocations for that matrix.

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IV. EXAMPLE OF EACH ALLOWANCE DETERMINATION MODEL

A. INTRODUCTION

The TIGER programs in Appendix C automatically compute repair part allowances and run simulations using those allowances under the operating scenarios specified in the input data. The output produced are in three sections:

1) the input deck printout;

2) the allowance computation output; and

3) the simulation output.

The input deck printout and simulation output have the same format for all three allowance determination models and are explained in detail in Reference 4, section 4. The allowance computation output was added for this research effort and is different for each of the allowance determination models. The allowance computation outputs are discussed in detail in this chapter. Comparisons between the effectiveness of the three allowance determination models are made in Chapter 5.

The system shown in Figure 4.1 will be used to demonstrate the processing of each allowance determination model. Each of the eight parts are assumed to be unique and have the unit prices and MTBFs shown. The allowances being developed are to sustain operations for 90 days. The format in which the data is input into the programs in Appendix C is discussed in detail in Appendix B.
Table V is the allowance computation output for an unconstrained .25 FLSIP model allowance for the system in Figure 4.1. For an unconstrained FLSIP allowance, the budget specified must be large enough to ensure that all insurance items will have an allowance equal to one and that all demand based items will have an allowance adequate to satisfy 90% of all expected demands during a 90 day period as discussed in Chapter 3, section A.

The first line of output shown is the budget constraint being used. This is shown after the letters "BUDR" which stand for "Budget-High Limit". In our example, the budget
constraint is $10,498.95. This is 5% higher than the actual budget constraint of $10,000 which was input. A 5% flexibility in the budget constraint was selected to ensure that any FLSIP computations that would be just slightly over the constraint specified would still be used for comparison purposes. This was done to ensure the FLSIP model compares as favorably as possible.

TABLE V

FLSIP Example: Allowance Computation Output

<table>
<thead>
<tr>
<th>BUDH 10,498.95</th>
<th>SPARES BEING COMPUTED USING FLSIP</th>
<th>XAVAIL = 0.9000</th>
<th>XSUM = 3058.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPARES TYPE</td>
<td>SHIP</td>
<td>TENDER</td>
<td>BASE</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The next two lines of output specify that the FLSIP model is being used and what availability probability was used to determine the .25 FLSIP allowances. All computations start at the 90% level (ie-computations produce allowances adequate to provide a 90% probability that the ship will have as many repair parts as demands for repair parts during any given 90 day period of time).

The fourth line of output is the total cost of all allowances required to satisfy the probability level previously specified. This cost is shown after the letters 35
"XSUM". If XSUM is less than or equal to BUDM, then the repair parts computed during that step will be used as the repair parts for this model. If XSUM is greater than BUDM, then the probability level will be reduced by 5% and another set of repair parts will be computed. In our example, XSUM for the 90% probability level is $3058.00 which is less than the budget limit of $10498.95 so the repair parts computed for this level are used.

The number of spare parts are the last thing shown on this part of the output page. In our example, item numbers (spares type) 1, 6, 7 and 8 are each assigned one shipboard spare, item numbers 2 and 5 are each assigned three shipboard spares and item numbers 3 and 4 are each assigned five shipboard spares.

For this research, it was assumed that no support could be received from sources other than the shipboard allowances so no spares are assigned to the tender or base levels of supply. The 999.00 in the "FACTOR" column indicates that the allowances shown were determined by the program instead of specified so the 999.00 should be ignored. When spares are specified, the number in this column is a spares multiplier which is explained fully in Appendix B under Card Type 18.

C. EXAMPLE OF A 100% FUNDED MARGINAL ANALYSIS MODEL

When the Marginal Analysis model uses the total costs of an unconstrained .25 FLSIP model allowance as the budget constraint, it is referred to as a 100% funded Marginal Analysis model. For the system in Figure 4.1, the cost of the allowances computed using the unconstrained .25 FLSIP model were $3058.00; so $3058.00 will be used as the budget constraint for the 100% funded marginal analysis model processing for that system.
Marginal Analysis Example: Allowance Determination Output

<table>
<thead>
<tr>
<th>SPARES Type</th>
<th>SPARES WILL BE DETERMINED WITH MARGINAL ANALYSIS</th>
<th>SPARES HAVE BEEN COMPUTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BUDGET IS 3058.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>THE COST OF Item 1 IS 150.00</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>THE COST OF Item 2 IS 151.00</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>THE COST OF Item 3 IS 152.00</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>THE COST OF Item 4 IS 153.00</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>THE COST OF Item 5 IS 154.00</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>THE COST OF Item 6 IS 155.00</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>THE COST OF Item 7 IS 156.00</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>THE COST OF Item 8 IS 157.00</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>ALL SPARES HAVE BEEN COMPUTED</td>
<td></td>
</tr>
</tbody>
</table>

The allowance computation outputs for a Marginal Analysis allowance determination model are different from those for the FLISIP model as shown on Table VI. The first line of output for the Marginal Analysis model is the statement that spares are determined using Marginal Analysis. The budget constraint and unit cost of each item are then printed as well as a statement indicating that all allowances have been computed. The allowance quantities are printed last. For the marginal analysis model, item numbers 6 and 7 are each assigned one spare, item number 8 is assigned two spares, item numbers 2 and 5 are each assigned three spares, item number 4 is assigned four spares, item 3
is assigned five spares and item number 7 is not assigned any spares. Note the differences in the allowances computed using the FLSIP and Marginal Analysis models. The total cost of the allowances determined by the Marginal Analysis model are only $2912.00 compared to $3058.00 for the FLSIP model because the next most cost effective part would have made the total investment in the Marginal Analysis model higher than that of the FLSIP model. Since the system presently in use is the FLSIP system, all unavoidable advantages in comparisons were given to the FLSIP system.

D. **EXAMPLE OF A 100% FUNDED AVAILABILITY MODEL**

When the Availability model also uses the total costs of an unconstrained .25 FLSIP model allowance as the budget constraint, then the Availability model is referred to as a 100% funded Availability model.

The allowance computation outputs for the Availability allowance determination model are different from the other models as shown on Table VII. The first line of output for the Availability model is the statement that spares were computed using the JEE formula. JTIME and TOTSPR are simply printouts of the input data on the JEE Data card. JTIME equals the number of hours simulated (90 days X 24 hours) and TOTSPR is the maximum number of spares which can be considered for any one repair part; for this example the TOTSPR used was 9. The availability matrix for each spare is then computed. After the availability matrix for the last spare has been printed, the output will indicate that the JEE algorithm has been entered.

Table VII shows the optimal allowances for the 100% funded availability model for the system in Figure 4.1. Item numbers 1, 6 and 7 are each assigned two spares, item number 8 is assigned four spares, item numbers 2 and 5 are
### Table VII

**Availability Model: Allowance Determination Output**

**Spares Being Computed Using JEE Formula**

**JTime is 2160**

**TotSPR is 9**

**Availability Matrix for Spare 1 is:**

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**JEEALG SUBROUTINE HAS BEEN ENTERED**

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40
each assigned five spares, and item numbers 3 and 4 are not assigned any spares.

If an optimal combination of spares can be determined by the algorithm, the last output will show the quantities of spares computed. However, there are two reasons why the computation of an optimal combination of spares may not be possible. First, the program can handle a maximum of only 9 spares for any given repair part. So, if the optimal solution has any repair parts with more than 9 spares, it cannot be computed. Second, the maximum number of undominated combinations which can be handled by the program is 99 and, if more than 99 undominated combinations are required in any matrix to reach the desired budget constraint, then the optimal solution cannot be computed. If this condition exists, the output will print: "OPTIMAL SOLUTION CANNOT BE COMPUTED". Even though an optimal solution cannot be computed, a set of spare parts will be generated and printed. It should be remembered however that these allowances are not optimal.

2. BUDGET CONSTRAINED EXAMPLES

Any dollar amount can be used as a budget constraint for the three allowance determination models. The FLSIP model will not compute allowances any higher than required to meet its insurance and availability objectives and therefore may not use all funds available. The marginal analysis and availability models will keep assigning spares until the budget constraint is reached.

For this research effort, the performance of the models was observed at budget constraints which were less than necessary to provide fully funded .25 FLSIP allowances. Examples are provided below for the allowance computation outputs for the three models using a budget constraint equal
to 75% of the costs of an unconstrained .25 FLSIP allowance for the system in Figure 4.1. The 75% budget constraint is equal to $2295.00.

The allowance computation outputs for the 75% funded .25 FLSIP model are shown on Table VIII. The program had to compute allowances at six different availability levels before it found one that would produce allowances costing less than the budget constraint (see Chapter 3, section A, for an explanation of this process). At the 90% and 95% availability levels, the allowances computed would cost $3058.00, and at the 80%, 75%, and 70% availability levels, the allowances computed would cost $2448.00. Different availability levels can have the same costs as discussed in detail in Chapter 3, section A. All of these allowance alternatives are more costly than the allowed budget. Not until the computation of the 65% availability level is an allowance combination reached (costing $2143.00) which is less than the budget constraint. The combination of repair parts computed as the 65% allowance level is then used in the TIGER simulation program to compute availabilities.

The allowance computation outputs for the 75% funded Marginal Analysis model are shown on Table IX. The only differences in the output for the 75% funded model and the 100% funded model (Table VI) are the budget constraint used and the allowances specified. The printout for the marginal analysis model does not show the different steps the program is going through to determine the allowances as does the .25 FLSIP model. However, the constrained runs do produce different allowances as can be seen by comparing Tables VI and IX. The 75% funded allowances have one additional spare for item number 1 but have one less spare for item numbers 2, 3, 4, 5 and 8.
TABLE VIII

FLSIP Example (75% funding): Allowance Determination Output

BUDG 2405.75
SPARES BEING COMPUTED USING FLSIP

\[ \begin{align*}
X\text{AVAIL} & = 0.9000 \\
X\text{SUM} & = 3058.00 \\
X\text{AVAIL} & = 0.8500 \\
X\text{SUM} & = 3058.00 \\
X\text{AVAIL} & = 0.8000 \\
X\text{SUM} & = 2448.00 \\
X\text{AVAIL} & = 0.7500 \\
X\text{SUM} & = 2448.00 \\
X\text{AVAIL} & = 0.7000 \\
X\text{SUM} & = 2448.00 \\
X\text{AVAIL} & = 0.6500 \\
X\text{SUM} & = 2143.00
\end{align*} \]

FLSIP ALLOWS CONSTRAINED BY BUDGET, XAVAIL = .850000

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</table>

The allowance computation outputs for the 75% funded Availability model are shown on Table X. The outputs are the same as for the 100% funded Availability model (Table VII) except for the allowances determined. Like the
Funded Marginal Analysis Example: Allowance Determination Output

Marginal Analysis model, the Availability model does not show the different steps the program is going through to determine the allowances.
### TABLE X

75% Funded Availability Example: Allowance Determination

**Output**

**SPARES BEING COMPUTED USING JEE FORMULA**

**JTIME IS** 2160

**TOTSPR IS 9**

**AVAILABILITY MATRIX FOR SPARE 1 is:**

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**AVAILABILITY MATRIX FOR SPARE 8 is:**

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**JEEALG SUBROUTINE HAS BEEN ENTERED**

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</tbody>
</table>
V. EVALUATION AND COMPARISON OF THE MODELS

A. SYSTEMS USED FOR EVALUATION

The four systems shown on Figures 5.1 through 5.4 were used to evaluate the three allowance determination models. The systems were selected to illustrate the relative effectiveness of the models in situations where the degree of designed-in system redundancy differs significantly. For example, System A has no designed-in redundancy and will fail whenever any one of the eight components fails whereas System D has a significant degree of designed-in redundancy and will not fail as long as components 1, 8 and 6 or 7 don't fail or components 1, 8 and 2 or 3 and 4 or 5 don't fail.

![Diagram of System A and System D](https://example.com/diagram)

**Figure 5.1** System A
Figure 5.2  System B

Figure 5.3  System C
B. SCENARIOS USED FOR EVALUATION

The twenty-seven different scenarios shown in Table XI were used in evaluating the three allowance determination models for each of the four systems discussed above.

Since the Marginal Analysis and Availability models explicitly consider component costs and MTBF as part of the allocation algorithms, the three models were compared on systems having a range of variabilities in component unit costs and MTBFs. Any advantages offered by algorithms which consider unit costs should be most apparent for cases in which unit cost variabilities are high. Likewise, any
TABLE XI

Test Scenarios

(Cases are defined in Figures 5.5 and 5.6)

<table>
<thead>
<tr>
<th>Case</th>
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<th>Case</th>
<th>Case</th>
<th>Case</th>
<th>Case</th>
<th>Case</th>
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<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
<td>C</td>
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<td>C</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part Cost</th>
<th>MTBF</th>
<th>Variance</th>
<th>Variance</th>
<th>100% Funding *</th>
<th>75% Funding *</th>
<th>50% Funding *</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

* based on the budget for the Unconstrained .25 FLSIP allowance list
advantages offered by algorithms which consider the MTBFs of the parts in the system should be most apparent for cases in which MTBF variances are high. So as not to bias the results in favor of any given model, comparisons were also made for cases in which the variability in unit costs and MTBFs were low. The three different sets of part costs shown in Figure 5.5 and the three sets of part MTBF data shown in Figure 5.6 were evaluated.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Case A</th>
<th>Case B</th>
<th>Case C</th>
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<tr>
<td>1</td>
<td>$150.00</td>
<td>$150.00</td>
<td>$50.00</td>
</tr>
<tr>
<td>2</td>
<td>151.00</td>
<td>200.00</td>
<td>400.00</td>
</tr>
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<td>3</td>
<td>152.00</td>
<td>100.00</td>
<td>500.00</td>
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<tr>
<td>4</td>
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<td>7</td>
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</tr>
<tr>
<td>8</td>
<td>157.00</td>
<td>150.00</td>
<td>50.00</td>
</tr>
</tbody>
</table>

Mean: 153.50 125.00 250.00
Standard Deviation: 2.45 59.76 217.12

Figure 5.5  Part Cost Sets

Since the Marginal Analysis and Availability models are designed to accommodate funding restrictions and the FLSIP model is not, any advantages offered by the former models should be most apparent for cases in which funding constraints are severe. So as not to bias the results in favor of the alternative models, comparisons were also made for systems where funds were adequate to fully fund FLSIP allowances. Thus, the allowances provided by each model for each combination or scenario of part costs and MTBFs were
determined for 100% (unconstrained), 75%, and 50% funding levels. The unconstrained funding level was based on a fully funded .25 FLSIP allowance for each scenario.

The parts required for a .25 FLSIP allowance to support each system under each scenario were determined first. The cumulative cost of those parts was then established as the 100% funding level. This 100% funding figure was then used as a constraint to establish allowances for each scenario using the Marginal Analysis and Availability models. Next, the funding available was constrained to 75% and 50% of the unconstrained FLSIP funding level for each system and scenario. Spares allowances were determined by using each of the three models for a given constrained funding.

C. TEST RESULTS

The results of running the TIGER simulations for the four systems and the 27 scenarios discussed above are shown in Tables XIII and XIII. Each system was simulated over 1000
missions (the maximum allowable in the TIGER simulator). A random number seed of 2222 was used for all simulations. The results include both average availability and instant availability.

Of the three allowance determination models, the availability model is the only one which considers system design. The advantages of considering system design when computing repair part allowances are clear in the example used in Chapter 4 (see Figure 4.1). That system is referred to in this chapter as the "B" system. The cost data and MTBF correspond to cases 1 and 3, respectively. The allowances computed by each allowance determination model for the "B" system are shown in Figure 5.7.

Since the FLSIP system ignores configuration, it assigns the highest number of spares (5 each) to part numbers 3 and 4 since they are expected to fail the most often and are therefore assumed to need the most support. Since the costs of the parts in this system are almost identical, the marginal analysis model essentially assigns spares (in this situation) to those parts which are expected to fail the most since that maximizes the number of demands that will be filled. This procedure results in almost the same allowances as the FLSIP model.

The Availability model recognizes that there is a more reliable parallel leg which can be supported more cost-effectively and therefore assigns no spares to part numbers 3 and 4. This action leaves extra money available to provide additional support to the other non-redundant parts in the system and results in a 10% improvement in system availability over the FLSIP model allowances and an 8% improvement in system availability over the Marginal Analysis model allowances. The availabilities, both average and instantaneous, listed in Tables XII and XIII are 89/91/98.
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TABLE XII
Percent System Availability Achieved

AVERAGE AVAILABILITY

<table>
<thead>
<tr>
<th>Case</th>
<th>Part</th>
<th>Cost</th>
<th>MTBF</th>
<th>Fund (FLSIP/Marginal Analysis/Availability)</th>
<th>AVERAGE AVAILABILITY</th>
<th>Sys A</th>
<th>Sys B</th>
<th>Sys C</th>
<th>Sys D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
<td>41/41/41</td>
<td>57/57/59</td>
<td>69/69/78 75/75/75</td>
<td>90/90/90</td>
<td>94/94/96</td>
<td>97/97/99</td>
<td>97/97/99</td>
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</tr>
<tr>
<td></td>
<td>50</td>
<td>41/41/41</td>
<td>57/57/59</td>
<td>69/69/78 75/75/75</td>
<td>90/90/90</td>
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<tr>
<td>C</td>
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<td>75</td>
<td>71/71/71 94/94/96 97/97/99 97/97/99</td>
<td>90/90/90</td>
<td>94/94/96</td>
<td>97/97/99</td>
<td>97/97/99</td>
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<tr>
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<td>57/57/59</td>
<td>69/69/78 75/75/75</td>
<td>90/90/90</td>
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<td>97/97/99</td>
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<tr>
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<td>57/57/59</td>
<td>69/69/78 75/75/75</td>
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<td>69/69/78 75/75/75</td>
<td>90/90/90</td>
<td>94/94/96</td>
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<td>94/94/96</td>
<td>97/97/99</td>
<td>97/97/99</td>
<td></td>
</tr>
</tbody>
</table>

FLSIP MA AVA

Total %
Greater Than
90% Availability

|      | 50 | 46 | 65 |

a - budget constraint was too low to compute a FLSIP allowance
b - optimal combination could not be reached

54
The overall results of the Marginal Analysis model were somewhat disappointing. For the data collected in Tables XII and XIII, the Marginal Analysis model outperformed the FLSIP model only 37% of the time for average availability (FLSIP did better 43% of the time and they tied 20% of the time) and 31% of the time for instant availability (FLSIP did better 16% of the time and they tied 53% of the time). It also achieved greater than 90% average availability only 46% of the time compared to 50% of the time for FLSIP and 65% of the time for the Availability model. Because of the relatively poor performance of this model compared to the FLSIP model, no further analyses will consider the Marginal Analysis model.

As would be expected, the improvements produced by the Availability model over the FLSIP model are always greater in instant availability than in average availability because the Availability model was designed to optimize instant availability. However, the Availability model also always resulted in the same or higher average availability than did the FLSIP model. Of course, in a given simulation, one might observe that the FLSIP model produces higher availability than does the Availability model just due to chance fluctuation. Indeed this happened for scenarios Case B/Case 1 for 50% funding, Case C/Case 1 for 50% funding, and Case A/Case 2 for 100% funding under System A on Table XII. Subsequent simulation runs using different random number seeds yielded the expected results with the Availability model outperforming the FLSIP model with respect to system availability.

As shown on Table XIV, the level of part cost variance has little influence on availability under the FLSIP model while the level of MTBF variance does significantly affect availability. This is as expected since the FLSIP model
TABLE XIII
Percent System Availability Achieved

INSTANT AVAILABILITY

<table>
<thead>
<tr>
<th>Part</th>
<th>Cost</th>
<th>MTBF</th>
<th>Fund(FLSIP/Marginal Analysis/Availability)</th>
<th>Case</th>
<th>Case</th>
<th>Sys A</th>
<th>Sys B</th>
<th>Sys C</th>
<th>Sys D</th>
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<tbody>
<tr>
<td>A 1</td>
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<td>72/72/72</td>
<td>94/94/96</td>
<td>97/97/99</td>
<td>97/97/99</td>
<td>97/97/99</td>
<td>75/75/75</td>
<td>97/97/99</td>
<td></td>
</tr>
<tr>
<td>B 1</td>
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<td>57/57/57</td>
<td>94/94/96</td>
<td>97/97/99</td>
<td>97/97/99</td>
<td>97/97/99</td>
<td>75/75/75</td>
<td>97/97/99</td>
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<table>
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<th>FLSIP</th>
<th>MA</th>
<th>AVA</th>
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<tbody>
<tr>
<td>Total % Greater Than 90% Availability</td>
<td>20</td>
<td>21</td>
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</table>

a - budget constraint was too low to compute a FLSIP allowance
b - optimal combination could not be reached

56
Figure 5.7 Allowances for Sample System

<table>
<thead>
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<th>Allowance Determination Model</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>1</td>
<td>1</td>
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<td>0</td>
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<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

The table shows the allowances for sample systems under different determination models. The FLSIP model and the Marginal Analysis model are compared to the Availability model. The Availability model appears to have a higher percentage improvement in system availability.

Does explicitly consider MTBF (through the demand rate) but it does not consider part costs.

As shown on Table IV, the part cost variability has some effect on system availability when the availability model is used. However, the variability in MTBF's has a much more significant effect. Since the systems evaluated in Table IV are fully funded systems, it appears that in the Availability model the influence of MTBF variance and system configuration are much more important in determining parts allowances than part costs are when the system is relatively well funded.

For both the FLSIP model and the Availability model, the level of availability improves as the systems become more redundant. The general improvement in availability as system redundancy increases is expected from reliability theory. As shown on Table XV, the percentage improvement with the Availability model is much higher than with the FLSIP model. This could also be anticipated since the Availability model is an optimization model which would increasingly enhance the reliability of a system as the system became more and more reliable itself; while the FLSIP model would provide the same level and type of support to
TABLE XIV
Average Availability: Actual MTBF Used to Compute Allowances
(100% Fully Funded Scenarios)

<table>
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<th>MTBF Case</th>
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<th>Low Redun</th>
</tr>
</thead>
<tbody>
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<td>PLSIP</td>
<td>AVA</td>
</tr>
<tr>
<td></td>
<td>1 2 3</td>
<td>1 2 3</td>
</tr>
<tr>
<td>Part Cost Case</td>
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<td></td>
</tr>
<tr>
<td>Case A</td>
<td>90 83 83</td>
<td>90 82 83</td>
</tr>
<tr>
<td>Case B</td>
<td>90 83 83</td>
<td>90 85 84</td>
</tr>
<tr>
<td>Case C</td>
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<table>
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</tr>
<tr>
<td>Case C</td>
<td>97 99 91</td>
<td>99 99 a</td>
</tr>
</tbody>
</table>

a - no optimal solution could be found using the JEE algorithm programmed for this research.

all systems regardless of how reliable the system might be. This results in providing support to components for which additional support is not needed at the expense (tradeoff) of not having extra support in areas which could use it.
### TABLE XV

Percent Decrease in Unavailability By Using Availability Allowances Vice FLSP

<table>
<thead>
<tr>
<th>Part</th>
<th>Cost Vari Var</th>
<th>Case</th>
<th>Fund</th>
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<th>Low Redun</th>
<th>Med Redun</th>
<th>Hi Redun</th>
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<tbody>
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<td>57</td>
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</table>

<table>
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<tr>
<th>Percent Improvement</th>
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<tr>
<td></td>
<td>30</td>
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</tr>
</tbody>
</table>

- FLSP allowances could not be computed at budget constraint specified.
- NOPT - an optimal solution could not be obtained using the Availability Model.
The FLSIP system is designed to have a 90% probability of not running out of a specific part during a 90 day mission. This part availability goal cannot be converted directly to an equipment availability goal; however it is of interest to compare how often systems were available at least 90% of the time under each model. As shown at the bottom of Table XII for average availability, allowances developed using the .25 FLSIP model achieved 90% availability only 50% of the time while allowances developed using the Availability model achieved 90% availability 65% of the time. For instant availability, the .25 FLSIP model achieved 90% availability only 20% of the time while allowances developed using the Availability model achieved 90% availability 52% of the time as shown on Table XIII. The Availability model shows its greatest advantage over FLSIP for cases in which less than 100% funding was available as shown in Figure 5.8.

<table>
<thead>
<tr>
<th>Funding Level</th>
<th>FLSIP Model</th>
<th>AVA Model</th>
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<tbody>
<tr>
<td>100%</td>
<td>89%</td>
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</tr>
<tr>
<td>75%</td>
<td>56%</td>
<td>83%</td>
</tr>
<tr>
<td>50%</td>
<td>16%</td>
<td>58%</td>
</tr>
</tbody>
</table>

Figure 5.8 Percentage of Times Allowances Achieved 90% Average System Availability

D. INACCURATE INPUT DATA

One measure of interest when evaluating mathematical models is the "robustness" of the models. That is, how well do the models work when there are deviations from the
assumptions upon which the models are derived. This section examines one such robustness issue. The effectiveness results of the three models are compared for the hypothetical case in which the values input for the MTBF parameters are assumed to be in error. Simulations were run with the 100% funded allowances where the usage rate was assumed to actually be twice as high (MTBF is half as high) as the figures used above to compute the allowances. The results of those simulations are shown on Table XVI.

As before, the effectiveness results are better with the Availability model than with the FLSIP model. However, the improvement afforded by the Availability model is even greater when the MTBF values are lower as shown on Table XVII. In the results summarized in Table XVI, only 17% of the scenarios using FLSIP model allowances achieved an equipment availability of 90% or better while more than 44% of the scenarios using Availability model allowances achieved the 90% criteria. The better performance of the Availability model in this situation is to be expected since it will focus support on those items which are most critical to the operation of the system at the expense of those components which are redundant. Then, since repair parts are concentrated in the critical components, failures more frequent than expected will not have as serious effect on system availability in contrast to the FLSIP model which attempts to cover all the bases.

Repair parts allowances determined using the Availability model often resulted in a smaller range of repair parts being carried than under the FLSIP model. This was particularly true when a severe budget constraint was imposed. For example, the unconstrained .25 FLSIP allowances and the Availability allowances for System D with Case B Part Costs and Case 2 MTBFs are shown in Figure 5.9. Both
### TABLE XVI

Inaccurate MTBF Data: Percent System Availability Achieved

#### Average Availability

<table>
<thead>
<tr>
<th>Part</th>
<th>Cost</th>
<th>MTBF</th>
<th>Fund</th>
<th>Var</th>
<th>Case</th>
<th>Case %</th>
<th>No Redun</th>
<th>Low Redun</th>
<th>Mid Redun</th>
<th>Hi Redun</th>
<th>FLSIP AVA</th>
<th>FLSIP AVA</th>
<th>FLSIP AVA</th>
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<td>86</td>
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<td>4/32</td>
<td>14/32</td>
<td>17%</td>
</tr>
<tr>
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<td>61</td>
<td>61</td>
<td>73</td>
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<td>58</td>
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<td>86</td>
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<td>4/32</td>
<td>14/32</td>
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</tr>
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<td>100</td>
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<td>73</td>
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<td>99</td>
<td>6/36</td>
<td>4/32</td>
<td>14/32</td>
<td>17%</td>
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<td>7/34</td>
<td>11/32</td>
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<td>7/34</td>
<td>11/32</td>
<td>9%</td>
</tr>
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<td>7/34</td>
<td>11/32</td>
<td>9%</td>
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<td>99</td>
<td>8/35</td>
<td>7/34</td>
<td>11/32</td>
<td>9%</td>
</tr>
<tr>
<td>B</td>
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<td>a</td>
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<td>82</td>
<td>76</td>
<td>99</td>
<td>77</td>
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<td>8/35</td>
<td>7/34</td>
<td>11/32</td>
<td>9%</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>100</td>
<td>52</td>
<td>a</td>
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<td>82</td>
<td>76</td>
<td>99</td>
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<td>99</td>
<td>8/35</td>
<td>7/34</td>
<td>11/32</td>
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</table>

#### Instant Availability

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<tr>
<th>Part</th>
<th>Cost</th>
<th>MTBF</th>
<th>Fund</th>
<th>Var</th>
<th>Case</th>
<th>Case %</th>
<th>No Redun</th>
<th>Low Redun</th>
<th>Mid Redun</th>
<th>Hi Redun</th>
<th>FLSIP AVA</th>
<th>FLSIP AVA</th>
<th>FLSIP AVA</th>
<th>FLSIP AVA</th>
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<tr>
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<td>4/32</td>
<td>14/32</td>
<td>17%</td>
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<td>9</td>
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<td>99</td>
<td>9/16</td>
<td>6/14</td>
<td>10/12</td>
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<td>36</td>
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<td>6/14</td>
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<td>6/14</td>
<td>10/12</td>
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<td>6/14</td>
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<td>6/14</td>
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<td>99</td>
<td>9/16</td>
<td>6/14</td>
<td>10/12</td>
<td>11%</td>
</tr>
</tbody>
</table>

#### Summary

Average Availability: FLSIP $\frac{6}{36} = 17\%$

Instant Availability: FLSIP $\frac{3}{36} = 8\%$

*a* - no optimal solution could be found using the Availability formula

---

62
**TABLE XVII**

Inaccurate MTBF Data: Percent Decrease in Unavailability

Percent Decrease in Unavailability Using Availability Model Instead of PLSIP Model

<table>
<thead>
<tr>
<th>Part</th>
<th>Cost</th>
<th>MTBF</th>
<th>Var</th>
<th>Var</th>
<th>Fund</th>
<th>Case</th>
<th>Case</th>
<th>% No Redun</th>
<th>Low Redun</th>
<th>Med Redun</th>
<th>Hi Redun</th>
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**Instant Availability**

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<th>Var</th>
<th>Var</th>
<th>Fund</th>
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<th>Case</th>
<th>% No Redun</th>
<th>Low Redun</th>
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<th>Hi Redun</th>
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<tbody>
<tr>
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<td>100</td>
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<td>92</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>100</td>
<td>Same</td>
<td>30</td>
<td></td>
<td>31</td>
<td></td>
<td>92</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>100</td>
<td>Same</td>
<td>66</td>
<td></td>
<td>71</td>
<td></td>
<td>96</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>100</td>
<td>Same</td>
<td>25</td>
<td></td>
<td>73</td>
<td></td>
<td>97</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>100</td>
<td>9</td>
<td>74</td>
<td></td>
<td>84</td>
<td></td>
<td>98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>100</td>
<td>9</td>
<td>10</td>
<td></td>
<td>87</td>
<td></td>
<td>99</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>3</td>
<td>100</td>
<td>11</td>
<td>55</td>
<td></td>
<td>92</td>
<td></td>
<td>99</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>100</td>
<td>NOPT</td>
<td>48</td>
<td></td>
<td>95</td>
<td></td>
<td>96</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOPT - no optimal solution could be found using the Availability formula**

of the above allowances cost exactly $1700.00. The FLSIP allowance resulted in average availability of .9925 while the Availability model allowances resulted in average availability of .9985; so that slightly better availability was achieved with only half the number of line items stocked by the Availability model. This phenomenon is not peculiar to this one case. The Availability model calculated fewer line items than the PLSIP model for every scenario in which the
system being evaluated had any designed-in redundancy. It also calculated fewer line items than the FLSIP model for about one-third of those systems which had no built-in redundancy. These results show that separate range and depth calculations are not necessarily needed in repair parts allowance determination models. The single criteria used by the Availability model implicitly excludes many items from range consideration by assigning them an allowance quantity of zero. The Marginal Analysis model reviewed in this research does the same thing.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FLSIP</strong></td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Availability</strong></td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**Figure 5.9 System D Allowances**
VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

The NAVSEA TIGER simulation model was modified in this thesis for use in evaluating three allowance determination models: the FLSIP model, the Marginal Analysis model, and the Availability model. The FLSIP model was originally included as part of the TIGER model so that FLSIP repair part allowances could automatically be computed if desired. Subprograms were written for this thesis so that repair parts for the other two models could automatically be computed by the TIGER model also. The modifications to the TIGER model made by Leather [Ref. 1: p.1] were utilized as well as his recommendation for converting BRF data into MTBF data for use in the TIGER model. The allowance computations and simulations were run on the IBM System 3033 located at the Naval Postgraduate School.

Four sample systems with varying degrees of designed-in redundancy were used to evaluate the effectiveness of the allowance determination models. Different combinations of unit cost and MTBF data were also used to evaluate the relative importance of these data elements in each of the models. And finally, different levels of funding availabilities were used to evaluate the robustness of each model with respect to funding constraints.

The effectiveness of each model for every system and scenario was obtained at three funding levels. First, the effectiveness of each model for each system/scenario combination was determined using a budget constraint equal to the cost of the allowances determined using an unconstrained .25 FLSIP model. Then the effectiveness of each model for each
system/scenario combination was determined using 75% and then 50% of the original amount.

The effectiveness of the allowance determination models was measured by the simulated availability of the systems being supported. The measures of effectiveness used were:

\[
\text{Average availability} = \frac{\text{Summation of Uptime for All Missions Simulated}}{\text{Summation of Total Mission Calendar Time for all Missions Simulated}}
\]

\[
\text{Instant availability} = \frac{\text{Number of Missions Up at Time (t)}}{\text{Total Number of Missions Simulated}}
\]

3. CONCLUSIONS

The Marginal Analysis model was not found to be significantly more effective than the FLSIP model and was decidedly less effective than the Availability model from an overall perspective. The Availability model was always at least as effective as the FLSIP model and it significantly outperformed the FLSIP model where funding constraints precluded 100% funded FLSIP allowances and where the MTBF were reduced by 50% to simulate a case of inaccurate failure rate data.

It was observed that changing the FLSIP cut point is not an effective method for accommodating budget constraints in systems with mostly high failure rate components. The FLSIP cut point is the dividing line between those low demand items which should be protected by an "insurance" allowance and those which should not. However, if all or most of the parts in a system have high enough demands to qualify for stocking on a demand based criteria, then changing the FLSIP cut point will not effect the number of these parts carried and therefore cannot be used to accommodate budget constraints. Use of the Availability model is a much more
effective method for accommodating budget constraints in these situations.

There was no significant difference in the effectiveness of systems supported by FLSIP determined allowances and Availability determined allowances when the system was non-redundant. As system redundancy increased, the availability improved for both FLSIP and Availability allowances. However, the magnitude of the improvement was significantly greater with the Availability allowances.

Fully funded .25 FLSIP allowances resulted in 90% system availability only 50% of the time even though the repair parts carried should theoretically have been sufficient to satisfy 90% of all repair part requests. Availability allowances at the same level of funding achieved 90% availability 65% of the time.

Repair part allowances determined using the Availability model often resulted in a smaller range of repair parts carried than did the FLSIP model. This was particularly true when a severe budget constraint was imposed. Finally, the Availability model incorporates both a range and depth capability illustrating that separate range and depth criteria are not required in all allowance determination models.

C. RECOMMENDATIONS

1. Further analysis of the Marginal Analysis model used in this research is not justified. Other marginal analysis models may be better and could be investigated in the same manner because of the ease in obtaining and entering the minimal amount of data required for this type of model.

2. System availability should be used as the measure of effectiveness for shipboard allowance determination models. This would require that a "standard" of effectiveness be
If the present FLSIP system meets the established availability goals then no further development of allowance determination systems would be required. On the other hand, if the present FLSIP system does not meet the established goals, then further development of an improved allowance determination system would be justified.

3. The use of the Availability model for determining shipboard repair part allowances should be further investigated. The importance of the various variables in the Availability model should be clarified. For example, is an improvement in repair time more important than an improved set of repair part allowances or are actual repair times really needed at all? The types of systems where availability can be improved the most should also be determined: i.e., systems with mostly high failure rate parts or low failure rate parts, systems with many components or only a few components, systems with a lot of designed in redundancy or only a little redundancy, etc. The TIGER simulator could be used to evaluate these various factors on a detailed basis.

4. The TIGER simulator or an improved version of a follow-on simulator should be used to evaluate the relative importance of the major factors in the shipboard operating environment which influence system availability (i.e., inaccurate MTBF reporting, configuration data, etc.). The TIGER simulator is easy to understand and easy to use. Once input data has been prepared, an allowance computation and simulation of 1000 missions can be run interactively on an IBM 3033 in two to six seconds of computer time. For example, it could be used to evaluate the effect of having bad BRB data when computing shipboard allowances using the FLSIP procedures to see how much emphasis should be placed on
obtaining better data. If equipment availability is relatively insensitive to inaccurate BRF data, then the improvement of data collection techniques can be ignored. If equipment availability is seriously degraded when BRF data is lower than actual failure rates, then the development of improved data collection techniques should be given a high priority. The TIGER simulator could also be used to evaluate what other factors in the logistics system are most pertinent in achieving better equipment availability so that emphasis can be placed on developing allowance determination models that include those important factors instead of factors that are less influential.
### APPENDIX A

#### ACRONYMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRF</td>
<td>Best Replacement Factor</td>
</tr>
<tr>
<td>FLSIP</td>
<td>Fleet Logistics Support Improvement Program</td>
</tr>
<tr>
<td>MTBF</td>
<td>Mean Time Between Failure</td>
</tr>
<tr>
<td>MTTR</td>
<td>Mean Time To Repair</td>
</tr>
<tr>
<td>NAVSEA</td>
<td>Naval Sea Systems Command</td>
</tr>
<tr>
<td>POP</td>
<td>Item Population</td>
</tr>
<tr>
<td>SPCC</td>
<td>Navy Ships Parts Control Center</td>
</tr>
</tbody>
</table>
APPENDIX B

AMENDED TIGER PROGRAM INPUT REQUIREMENTS

The punched cards or card images discussed in this appendix must be input to utilize the NAVSEA TIGER program as amended for this research effort. A complete printout of the amended program is provided in Appendix C.
Card Type 1. Availability Model Processing Cards.

The Availability Model Processing Cards control the order in which the various parts in a system will be combined to compute optimal repair part allowances for the system when the Availability Model is being used. The first step in preparing this card is to complete a system reliability block diagram similar to Figure B.1.

![Diagram](image)

**Figure B.1 Block Diagram Example**

Once an accurate reliability block diagram has been prepared, the system availabilities resulting from combining all the individual parts must be computed. This is done by starting with two parts and progressively combining additional parts until all of the parts have been combined. To properly prepare the Availability Model Processing Cards, the system must be analyzed to determine how the individual
components can be combined so that there are never more than two sets of parts combinations. For example, the parts in the system in Figure 3.1 could be combined in the following manner:

\[\text{Combination \#1} = (\text{Part 2}) \text{ and } (\text{Part 3})\]

\[\text{Next Combination \#1} = \text{Previous Combination \#1 and (Part 1)}\]
\[= (\text{Parts 2,3}) \text{ and } (\text{Part 1})\]

\[\text{Next Combination \#1} = \text{Previous Combination \#1 and (Part 4)}\]
\[= (\text{Parts 1,2,3}) \text{ and } (\text{Part 4})\]

\[\text{Combination \#2} = (\text{Part 5}) \text{ and } (\text{Part 6})\]

\[\text{Next Combination \#1} = \text{Previous Combination \#1 and Previous Combination \#2}\]
\[= (\text{Parts 1,2,3,4}) \text{ and } (\text{Parts 5,6})\]

\[\text{Next Combination \#2} = (\text{Part 7}) \text{ and } (\text{Part 8})\]

\[\text{Next Combination \#1} = \text{Previous Combination \#1 and Previous Combination \#2}\]
\[= (\text{Parts 1,2,3,4,5,6}) \text{ and } (\text{Parts 7,8})\]
They could not be combined in the following manner even though the parts combinations are appropriate because the use of three combinations is not allowed:

Combination #1 = (Part 2) and (Part 3)

Next Combination #1 = Previous Combination #1 and (Part 1)
= (Parts 2, 3) and (Part 1)

Next Combination #1 = Previous Combination #1 and (Part 4)
= (Parts 1, 2, 3) and (Part 4)

Combination #2 = (Part 5) and (Part 6)

Combination #3 = (Part 7) and (Part 8)

Next Combination #2 = Previous Combination #2 and Previous Combination #3
= (Parts 5, 6) and (Parts 7, 8)

Next Combination #1 = Previous Combination #1 and Previous Combination #2
= (Parts 1, 2, 3, 4) and (Parts 5, 6, 7, 8)

Once an appropriate flow of combinations has been determined for a system, the worksheet shown on Figure 8.2 should be prepared. The first spares to be combined will be shown next to combination 101. In addition, whether they are to be in series or parallel must be coded and all the parts included in the resulting combination should be specified. The next line will show the part number or combination number for the parts being combined in that step, whether they are in series or parallel, and which
Figure B.2 Availability Model Processing Card Worksheet

parts end up being included in that combination. This process is continued until all parts are included in the last combination. An example of a worksheet filled in for the proper combination of parts in Figure B.1 discussed above is shown in Figure B.3.

An individual Availability Processing Card must then be prepared for each line on the worksheet (in the format provided below). The cards must be input in the same order they appear on the worksheet. One additional card must be added at the end of this deck which has zeros in columns 4, 8 and 12 to signify that all combinations are complete. If the Availability model is not being used, these cards can be left in the input data or only the last card with the three zeros can be input.
The format and content of the individual cards are shown below. Note that only the 3 middle columns of Figure B.3 are entered. An example of the cards prepared from Figure B.3 is shown in Figure B.4.

### Table: Example of Worksheet

<table>
<thead>
<tr>
<th>Comb #</th>
<th>Part or Combin</th>
<th>Part or Combin</th>
<th>Ser(1)</th>
<th>Par(0)</th>
<th>Parts Included</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td></td>
<td>2,3</td>
</tr>
<tr>
<td>102</td>
<td>101</td>
<td>1</td>
<td>1</td>
<td></td>
<td>1,2,3</td>
</tr>
<tr>
<td>103</td>
<td>102</td>
<td>4</td>
<td>1</td>
<td></td>
<td>1,2,3,4</td>
</tr>
<tr>
<td>104</td>
<td>5</td>
<td>6</td>
<td>1</td>
<td></td>
<td>5,6</td>
</tr>
<tr>
<td>105</td>
<td>103</td>
<td>104</td>
<td>0</td>
<td></td>
<td>1,2,3,4,5,6</td>
</tr>
<tr>
<td>106</td>
<td>7</td>
<td>8</td>
<td>1</td>
<td></td>
<td>7,8</td>
</tr>
<tr>
<td>107</td>
<td>105</td>
<td>106</td>
<td>1</td>
<td></td>
<td>1,2,3,4,5,6</td>
</tr>
</tbody>
</table>

**Figure B.3 Example of Worksheet**

The format and content of the individual cards are shown below. Note that only the 3 middle columns of Figure B.3 are entered. An example of the cards prepared from Figure B.3 is shown in Figure B.4.

<table>
<thead>
<tr>
<th>Column</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>I4</td>
<td>J</td>
<td>The first of two parts or combinations to be combined for determining optimum combination of spares using the JEE algorithm.</td>
</tr>
<tr>
<td>5-8</td>
<td>I4</td>
<td>K</td>
<td>The second of two parts or combinations to be combined for determining optimum combination of spares using the JEE algorithm.</td>
</tr>
<tr>
<td>9-12</td>
<td>I4</td>
<td>SER</td>
<td>Indicates whether two systems being compared on this card are in series (set SER = 1) or in parallel (set SER = 0).</td>
</tr>
<tr>
<td>Column 1</td>
<td>Column 2</td>
<td>Column 3</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>11111111112222222233333334444444455</td>
<td>123456789012345678901234567890123456789012345678901</td>
<td>2 3 0</td>
<td></td>
</tr>
<tr>
<td>101 1 1</td>
<td>102 4 1</td>
<td>5 6 1</td>
<td></td>
</tr>
<tr>
<td>103 104 1</td>
<td>7 8 1</td>
<td>105 106 1</td>
<td></td>
</tr>
<tr>
<td>0 0 0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Card Type 2. Allowance Model Card.

This card is used to determine which allowance determination model is to be used to compute repair parts and to input budget data. The format and content of the individual cards are shown below. An example of this card for the system in Figure B.1 for FLSIP processing and a budget of $3,000.00 is shown in Figure B.5.

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>I4</td>
<td>NTOTA</td>
<td>Total number of parts in the system (must equal number of cost cards entered below). If cost cards are not to be entered, use 1 in card column 4 and include 1 cost card with a $1.00 cost.</td>
</tr>
<tr>
<td>5-8</td>
<td>F4.0</td>
<td>XFLAG</td>
<td>Used to select type of allowance determination system as follows:</td>
</tr>
<tr>
<td>9-16</td>
<td>F8.0</td>
<td>BUDGET</td>
<td>Budget to be used for computations. Max budget allowed is $99,999,999.00.</td>
</tr>
</tbody>
</table>

Card Columns:

```
1111111111122222222333333334444445555
123456789012345678901234567890123456789012
8 0.0 3000.00
```

Figure B.5 Allowance Model Card Example
Card Type 3. Cost Cards.

A separate Cost Card must be entered for each part in the format specified below. An example of these cards for the system in Figure B.1 is given in Figure B.6.

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-8</td>
<td>F8.2</td>
<td>Cost</td>
<td>Cost of each repair part. Costs must be input in the same order as equipment type numbers on Equipment Type cards. Total cards must equal NTOTA on Allowance Model Processing card. If cost data is not to be entered, use one card with a cost of $1.00.</td>
</tr>
</tbody>
</table>

Card Columns:

```
11111111112222222222333333333334444444445555
1234567890123456789012345678901234567890123456789012
100.00
100.00
150.00
500.00
2000.00
50.00
300.00
1000.00
```

Figure B.6 Cost Card Examples
Card Type 4. JEE Data Card.

The total mission time and the maximum number of spares allowed for each repair part must be input in the format described below. An example of a JEE Data card for the system in Figure B.1 is shown in Figure B.7 using a 90 day mission time (90 x 24 = 2160) and a maximum number of spares equal to nine.

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-8</td>
<td>I8</td>
<td>JTIME</td>
<td>Total Mission Time.</td>
</tr>
<tr>
<td>9-12</td>
<td>I4</td>
<td>TOTSPR</td>
<td>Total number of spares for which availability is to be computed using the availability model. Max is 9. If availability model is not to be used, insert 1 in card column 12.</td>
</tr>
</tbody>
</table>

Card Columns:

```
1111111111222222222233333333344444444555
123456789012345678901234567890123456789012
2160  9
```

Figure B.7 JEE Data Card Example
Card Type 5. Timeline Iteration Card

The number of timeline iterations to be used and the run identification data for the specific run being made are shown on this card. A timeline iteration of one was used for all the simulations done for this research. Additional information for using more than one timeline iteration may be found in reference 4, section 2. The format is described below. An example of a Timeline Iteration Card for the system in Figure B.1 is shown in Figure B.8.

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>I4</td>
<td>JCC</td>
<td>Number of timeline iterations to be run for the data deck.</td>
</tr>
<tr>
<td>5-80</td>
<td>19A4</td>
<td>RUNID</td>
<td>Alphanumeric run identification information.</td>
</tr>
</tbody>
</table>

Card Columns:

```
11111111112222222233333333334444444444555
123456789012345678901234567890123456789012
1.25 FLSIP RUN FOR SYSTEM B1 ON 5/20/82
```

Figure B.8 Timeline Iteration Card Example
Card Type 6. **Statistical Parameter Card.**

Statistical parameters for the run are entered on this card. If a predefined fixed number of missions is to be run, set PL = 1.0 and NOPT and NMAX to the desired number of missions. All simulations for this research were run with a fixed number of 1000 missions. If what is desired is to determine whether a system meets a certain level of reliability, that level can be specified in the PL and IK blocks and the simulator will run an adequate number of missions to determine whether the system will meet or fail to meet the specified reliability (PL) within the standard deviation specified (IK) [Ref. 4: p. 2-7]. An example of a Statistical Parameter Card for use with the system in Figure B.1 is shown in Figure B.9.

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>I4</td>
<td>NMAX</td>
<td>Maximum number of missions to be run (should be in multiples of 50 and must not exceed 1000).</td>
</tr>
<tr>
<td>5-8</td>
<td>I4</td>
<td>NOPT</td>
<td>Optimal number of missions (not to exceed NMAX).</td>
</tr>
<tr>
<td>9-12</td>
<td>F4.0</td>
<td>PL</td>
<td>Specification requirement for reliability.</td>
</tr>
<tr>
<td>13-16</td>
<td>F4.0</td>
<td>IK</td>
<td>Standard deviation to be used in calculating lower control limit. A value of 1.28 corresponds to a 90% lower confidence limit.</td>
</tr>
<tr>
<td>17-20</td>
<td>I4</td>
<td>ISEED</td>
<td>Random number seed.</td>
</tr>
<tr>
<td>21-24</td>
<td>I4</td>
<td>NPH</td>
<td>Number of phase types - not to exceed 6.</td>
</tr>
</tbody>
</table>
Card Columns:

<table>
<thead>
<tr>
<th>11111111112222222222333333333333344444444555</th>
</tr>
</thead>
<tbody>
<tr>
<td>12345678901234567890123456789012345678901234567890123</td>
</tr>
<tr>
<td>10001000 1.01.282222 1</td>
</tr>
</tbody>
</table>

**Figure B.9**  Statistical Parameter Card Example
Card Type 7: Phase Type and Duration Cards.

This card is used to specify the number of phase types and how long each is to last. The phases can be used to identify different scenarios. For example, for simulating shipboard operations: one phase can represent in-port periods, another can represent normal steaming operations, and a third can represent battle engagement periods. The repair option for each part can be different in each phase as specified on Card Type 10 and the Duty Cycle Utilization of each part can also be different during each phase as specified on Card Type 12. From 1 to 95 phase sequences of not more than six phase types can be specified on these cards. The format for this card is described below. For this research effort, a single phase lasting 90 days (2160 hours) was used for all simulations. An example of this type card is shown in Figure B.10.

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>F2.0</td>
<td>XXT(1)</td>
<td>Phase type number for first simulation sequence.</td>
</tr>
<tr>
<td>3-10</td>
<td>F8.0</td>
<td>XXT(2)</td>
<td>Duration of first sequence.</td>
</tr>
<tr>
<td>11-12</td>
<td>F2.0</td>
<td>XXT(3)</td>
<td>Phase type number for second simulation sequence (if any).</td>
</tr>
<tr>
<td>13-20</td>
<td>F8.0</td>
<td>XXT(4)</td>
<td>Duration of second phase.</td>
</tr>
<tr>
<td>21-22</td>
<td>F2.0</td>
<td>XXT(5)</td>
<td>Phase type number for third simulation sequence (if any).</td>
</tr>
<tr>
<td>23-30</td>
<td>F8.0</td>
<td>XXT(6)</td>
<td>Duration of third sequence.</td>
</tr>
<tr>
<td>31-32</td>
<td>F2.0</td>
<td>XXT(7)</td>
<td>Phase type number for fourth simulation sequence (if any).</td>
</tr>
<tr>
<td>33-40</td>
<td>F8.0</td>
<td>XXT(8)</td>
<td>Duration of fourth sequence.</td>
</tr>
<tr>
<td>41-42</td>
<td>F2.0</td>
<td>XXT(9)</td>
<td>Phase type number for fifth simulation sequence (if any).</td>
</tr>
<tr>
<td>43-50</td>
<td>F8.0</td>
<td>XXT(10)</td>
<td>Duration of fifth sequence.</td>
</tr>
</tbody>
</table>

Note: If more than 5 phase sequences are needed, continue on additional cards using the same fields. No more than 95 phase sequences are permitted.
Card Columns:

1111111122222333333344444555
1234567890123456789012345678901234567890123456789012345678901
1.2160.

Figure 8.10  Phase Type and Duration Card Example
Card Type 8. **** Blank Card ****

Card Type 2. Printout Option Card

This card is used to select which printout option is to be used. The format is as follows.

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
</table>
| 1-4     | I4     | KOPT          | Printout option switch  
          |         |               | = 1 for management summary  
          |         |               | = 2 for engineering summary  
          |         |               | = 3 for complete details  
          |         |               | (used for debugging only)  
          |         |               | = 4 to suppress printout of  
          |         |               | input data  
          |         |               | = 5 to specify printout using  
          |         |               | KS variables below  
          |         |               | = 6 for TIGER/MANNING complete  
          |         |               | details (debugging only) |

If KOPT 5 is used, select from the following output options as needed (otherwise leave the fields blank):

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-8</td>
<td>I4</td>
<td>KS(1)</td>
<td>= 1: Input data</td>
</tr>
</tbody>
</table>
| 9-12    | I4     | KS(2)         | = 1: equipment down at time of  
          |         |               | mission failure |
| 13-16   | I4     | KS(3)         | = 1: down time at end of phase |
| 17-20   | I4     | KS(4)         | = 1: abort messages |
| 21-24   | I4     | KS(5)         | = 1: all events |
| 25-28   | I4     | KS(6)         | = 1: ETINE matrix |
| 29-32   | I4     | KS(7)         | = 1: not used |
| 33-36   | I4     | KS(8)         | = 1: not used |
| 37-40   | I4     | KS(9)         | = 1: not used |
| 41-44   | I4     | KS(10)        | = 1: system & subsystem status |
| 45-48   | I4     | KS(11)        | = 1: TIGER/MANNING debugging |
| 49-52   | I4     | KS(12)        | = 1: status of all groups |
| 53-56   | I4     | KS(13)        | = 1: downtime message |
### Card Type 10: Phase Repair Card

This card is used to specify the repair option for each phase up to a total of six. The format is as follows:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>I4</td>
<td>IFLAG(1)</td>
<td>Repair option for each phase type (up to 6):</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>= 0 if on-board repair allowed in the phase</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>= 1 if no on-board repair allowed in the phase</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>= 2 if on-board repair allowed but failure inhibited</td>
</tr>
<tr>
<td>5-8</td>
<td>I4</td>
<td>IFLAG(2)</td>
<td></td>
</tr>
<tr>
<td>9-12</td>
<td>I4</td>
<td>IFLAG(3)</td>
<td></td>
</tr>
<tr>
<td>13-16</td>
<td>I4</td>
<td>IFLAG(4)</td>
<td></td>
</tr>
<tr>
<td>17-20</td>
<td>I4</td>
<td>IFLAG(5)</td>
<td></td>
</tr>
<tr>
<td>21-24</td>
<td>I4</td>
<td>IFLAG(6)</td>
<td></td>
</tr>
</tbody>
</table>
Card Type 11. Repair Policy Card.

This card is used to establish repair policy for the simulation being run. REPOL determines what percentage of repairs will be made at the shipboard level as opposed to the intermediate and depot level. Since this research evaluates shipboard support only, REPOL was set equal to 1.0 for all simulations.

A part can be allowed to fail for a certain period of time before its failure causes the system to be in a down status by specifying an allowable downtime in the TAD2 field. For this research, all mission allowable downtimes were set equal to zero.

Specified MTBFs and MTTRs can be changed for a given simulation run by using a value other than 1.0 in the XM and XT fields.

The format for the card is:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>F4.0</td>
<td>REPOL</td>
<td>Decimal fraction of repairs to be performed aboard ship</td>
</tr>
<tr>
<td>5-12</td>
<td>F8.2</td>
<td>TAD2</td>
<td>Mission Allowable Downtime</td>
</tr>
<tr>
<td>13-16</td>
<td>F4.0</td>
<td>XM</td>
<td>MTBF Multiplier. Default = 1.0</td>
</tr>
<tr>
<td>17-20</td>
<td>F4.0</td>
<td>XT</td>
<td>MTTR Multiplier. Default = 1.0</td>
</tr>
</tbody>
</table>
Card Type 12. Equipment Type Cards

Equipment type cards are used to input the specific parameters for each type of equipment (repair part) being evaluated. A separate card must be input for each type of equipment. The TIGER simulator can accommodate various equipment operating rules and variable duty cycles for each piece of equipment (these options were not utilized for this research). A detailed discussion of these items can be found in Reference 4, chapter 2. The format for these cards is provided below. An example of these cards for the system in Figure B.1 is shown in Figure B.11.

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>I4</td>
<td>I</td>
<td>Equipment type numbers—should be assigned sequentially starting at 1, not to exceed 200.</td>
</tr>
<tr>
<td>5-20</td>
<td>4A4</td>
<td>F1</td>
<td>Equipment type description</td>
</tr>
<tr>
<td>21-28</td>
<td>F8.0</td>
<td>XMTPBF</td>
<td>Mean Time Between Failure</td>
</tr>
<tr>
<td>29-32</td>
<td>F4.0</td>
<td>XMTR</td>
<td>Mean Time to Repair/Replace Non-repairable is indicated by 9999.</td>
</tr>
<tr>
<td>33-36</td>
<td>F4.0</td>
<td>U</td>
<td>Duty cycle utilization (non-zero decimal fraction)</td>
</tr>
<tr>
<td>37-40</td>
<td>F4.0</td>
<td>V</td>
<td>Administrative delay time from tender to ship</td>
</tr>
<tr>
<td>41-44</td>
<td>F4.0</td>
<td>W</td>
<td>Administrative delay time from depot to ship.</td>
</tr>
<tr>
<td>45-48</td>
<td>I4</td>
<td>IUI</td>
<td>Used for variable duty cycles. See Reference 4, chapter 2 for an explanation.</td>
</tr>
</tbody>
</table>
Card Columns:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Part 1</th>
<th>Part 2</th>
<th>Part 3</th>
<th>Part 4</th>
<th>Part 5</th>
<th>Part 6</th>
<th>Part 7</th>
<th>Part 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>250.00</td>
<td>150.00</td>
<td>750.00</td>
<td>150.00</td>
<td>750.00</td>
<td>150.00</td>
<td>750.00</td>
<td>250.00</td>
</tr>
</tbody>
</table>

Figure B.11 Examples of Equipment Type Cards

This is an optional card. It is used if variable duty cycles are used. See chapter 2 of Reference 4 for details of its use.

Card Type 14. Variable Mean Time to Repair Card.

This is an optional card. It is used if variable Mean Times to Repair are used. See chapter 2 of Reference 4 for details of its use.

Card Type 15. Blank Card
Card Type 16. Equipment Cards.

Each individual piece of equipment (repair part) in the system being evaluated must be given a unique number to identify it. These cards identify which equipment type each specific equipment (repair part) is. There must be one card for each equipment type and they must be input sequentially by equipment type number in the format specified below. For this research, the aspects of spares sharing were not considered because the calculations developed by JEE [Ref. 3], are different for scenarios where spares are shared. To use the Availability model developed for this research, each equipment number must be assigned its own equipment type even if the parameters for two or more equipments are identical.

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>I4</td>
<td>MTYPE</td>
<td>The type number associated with the equipment listed in the next field or fields.</td>
</tr>
<tr>
<td>5-8</td>
<td>I4</td>
<td>LOAD(1)</td>
<td>Equipment numbers of those equipment which belong to the designated equipment type.</td>
</tr>
<tr>
<td>9-12</td>
<td>I4</td>
<td>LOAD(2)</td>
<td>Up to 19 equipment per card.</td>
</tr>
<tr>
<td>13-16</td>
<td>I4</td>
<td>LOAD(3)</td>
<td>(If there are more than 19 equipment associated with a given type, use additional equipment cards and repeat the same type number). The largest equipment number allowed by the program is 500. The total number of equipments must not exceed 500. No gaps are allowed between equipment numbers.</td>
</tr>
<tr>
<td>17-20</td>
<td>I4</td>
<td>LOAD(4)</td>
<td>and the largest assigned equipment number.</td>
</tr>
<tr>
<td>21-24</td>
<td>I4</td>
<td>LOAD(5)</td>
<td></td>
</tr>
<tr>
<td>25-28</td>
<td>I4</td>
<td>LOAD(6)</td>
<td></td>
</tr>
<tr>
<td>29-32</td>
<td>I4</td>
<td>LOAD(7)</td>
<td></td>
</tr>
<tr>
<td>33-36</td>
<td>I4</td>
<td>LOAD(8)</td>
<td></td>
</tr>
<tr>
<td>37-40</td>
<td>I4</td>
<td>LOAD(9)</td>
<td></td>
</tr>
<tr>
<td>41-44</td>
<td>I4</td>
<td>LOAD(10)</td>
<td></td>
</tr>
<tr>
<td>45-48</td>
<td>I4</td>
<td>LOAD(11)</td>
<td></td>
</tr>
<tr>
<td>49-52</td>
<td>I4</td>
<td>LOAD(12)</td>
<td></td>
</tr>
<tr>
<td>53-56</td>
<td>I4</td>
<td>LOAD(13)</td>
<td></td>
</tr>
<tr>
<td>57-60</td>
<td>I4</td>
<td>LOAD(14)</td>
<td></td>
</tr>
<tr>
<td>61-64</td>
<td>I4</td>
<td>LOAD(15)</td>
<td></td>
</tr>
<tr>
<td>Period</td>
<td>Type</td>
<td>Event</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>65-68</td>
<td>I4</td>
<td>LOAD(16)</td>
<td></td>
</tr>
<tr>
<td>69-72</td>
<td>I4</td>
<td>LOAD(17)</td>
<td></td>
</tr>
<tr>
<td>73-76</td>
<td>I4</td>
<td>LOAD(18)</td>
<td></td>
</tr>
<tr>
<td>77-80</td>
<td>I4</td>
<td>LOAD(19)</td>
<td></td>
</tr>
</tbody>
</table>
This card is used to specify whether spares will be input directly or whether spares will be computed using one of the allowance determination models. The options for this card are:

a) Use the literal "Unlimited Spares" in columns 1 through 16 to simulate unlimited spares. The program then assigns 90,000 spares for each equipment or repair part. This option was not used during this research.

b) Use a blank card if spares are going to be specified. Then input the desired number of spares for each equipment or repair part on the spares cards which follow. (This option was used to simulate the use of inaccurate MTBF data by computing allowances with one set of MTBF data and then specifying those allowances using this option and inputting different MTBF parameters for comparison.) If spares have been specified and the effect of using a different level of support are needed, this effect can be obtained by inserting a spares multiplier (SI) in card columns 21 to 24 of this card. The program will then use the number of spares assigned times the spares multiplier specified.

c) Use "999." in columns 21 to 24 to use the allowance determination model specified on the Allowance Model card (Card Type 2).
AN EVALUATION OF ALLOWANCE DETERMINATION USING
OPERATIONAL AVAILABILITY(U) NAVAL POSTGRADUATE SCHOOL
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END
DATE
F/M
DTC
Card Type 19. Spares Cards.

These cards are only used if the allowances for spares are going to be specified exactly (columns 1 through 16 of the Spares Model card must be empty and columns 21 through 24 must have something other than .999). One of these cards must be input for each equipment type being used. These cards must be input in order starting with Equipment Type 1 in the following format:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>I4</td>
<td>ISPARE(1)</td>
<td>Number of organizational level spares (on board) for the equipment type.</td>
</tr>
<tr>
<td>5-8</td>
<td>I4</td>
<td>ISPARE(2)</td>
<td>Number of spares at the tender for the equipment type.</td>
</tr>
<tr>
<td>9-12</td>
<td>I4</td>
<td>ISPARE(3)</td>
<td>Number of spares at the base (depot) for the equipment type</td>
</tr>
</tbody>
</table>
NOTE: For each phase type, a set of the remaining cards (except the optional output and demo decks which appear once) must be placed consecutively in the data deck.

A separate reliability block diagram must be prepared for the simulation runs on the TIGER simulator. It is different than the reliability block diagram previously discussed for Availability model processing because it does not have to relate only two groups at a time. For the TIGER simulator, equipments must be aggregated into systems, subsystems, and groups. A system is a set of equipments for which availability is being measured. A subsystem is a set of equipments which, if the set fails, will cause the system to fail. A group is any set of equipments.

For the reliability block diagram for the TIGER simulator, each parallel subset of equipment and each series subset are assigned group numbers. For the example shown in Figure B.1, the groups could be as shown below. Group numbers must be between 501 and 1300 and are arbitrarily assigned below.

<table>
<thead>
<tr>
<th>Group Number</th>
<th>Equipments in Group</th>
<th>Series/Parallel</th>
</tr>
</thead>
<tbody>
<tr>
<td>501</td>
<td>2 and 3</td>
<td>Parallel</td>
</tr>
<tr>
<td>502</td>
<td>5 and 6</td>
<td>Series</td>
</tr>
<tr>
<td>503</td>
<td>7 and 8</td>
<td>Series</td>
</tr>
</tbody>
</table>

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Once each subset of parallel or series equipments has been assigned a group number, the identified groups are then aggregated into groups of groups which are in parallel or series and these groups are assigned numbers. For the equipments in Figure B.1, the next set of groups could look like those shown below.

<table>
<thead>
<tr>
<th>Group Number</th>
<th>Equipments in Group</th>
<th>Series/Parallel</th>
</tr>
</thead>
<tbody>
<tr>
<td>601</td>
<td>1, 4, and 501</td>
<td>Series</td>
</tr>
<tr>
<td>701</td>
<td>502 and 601</td>
<td>Parallel</td>
</tr>
<tr>
<td>888</td>
<td>503 and 701</td>
<td>Series</td>
</tr>
</tbody>
</table>

This process is continued until all the parts in the system can be identified in one group (known as a subsystem group). The subsystem groups are then combined with any remaining equipment which are in series and assigned a final group number (known as the system group). For our example, Group # 701 would be a subsystem group and the system group would be composed of subsystem group # 701 and the series group # 503. For illustrative purposes, the system group will be assigned Group number 888. The method for inputing these relationships into the TIGER simulator are discussed under card types 20 through 23.
Figure B.12  Example of System, Subsystem, and Group Numbering
Card Type 20. System Card.

This card is used to identify the different systems being evaluated. The format for this card is as follows:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>A4</td>
<td>ID</td>
<td>Any alphanumeric (i.e., the literal &quot;SYST&quot;) used to identify the specific system</td>
</tr>
<tr>
<td>5-8</td>
<td>I4</td>
<td>LL</td>
<td>Phase type number (sequential) The max value is 6.</td>
</tr>
<tr>
<td>9-12</td>
<td>I4</td>
<td>NSS</td>
<td>Number of subsystems in phase (varies only from 1 to 31).</td>
</tr>
<tr>
<td>13-16</td>
<td>I4</td>
<td>ISS</td>
<td>System identification number (usually last group number on the configuration matrix cards).</td>
</tr>
<tr>
<td>17-24</td>
<td>F8.0</td>
<td>STIME</td>
<td>System allowable sustained down time (should not be less than subsystem TAD1 values); Should be less than or equal to TAD2 (repair policy card). To inhibit aborts use a value of 100,000.</td>
</tr>
</tbody>
</table>

An example of the System Card for the system in Figure 8.12 is:

```
Card Columns:
1111111111222222222223333333333333344444444455
123456789012345678901234567890123456789012345678901
SYST 1 1 888 0.0
```
Card Type 21: Subsystem Cards.

This card is used to identify the different subsystems being evaluated. The format for this card is as follows:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>A4</td>
<td>ID</td>
<td>Any alphanumeric (i.e. the literal &quot;SS1&quot;).</td>
</tr>
<tr>
<td>5-8</td>
<td>I4</td>
<td>LL</td>
<td>Phase type number.</td>
</tr>
<tr>
<td>13-16</td>
<td>I4</td>
<td>ISS</td>
<td>Subsystem identification number. This is a group number for a group defined on a configuration matrix card (see below). Each designated subsystem group must be a group that, upon its failure, causes the system to fail.</td>
</tr>
<tr>
<td>17-24</td>
<td>F8.0</td>
<td>SSTIME(2)</td>
<td>Subsystem allowable sustained downtime (TAD). This value should be less than or equal to SSTIME on the system card. To inhibit aborts use a value of 100,000.</td>
</tr>
</tbody>
</table>

An example of the Subsystem Card for the system in Figure B.12 is:

```
Card Columns:
111111111122222222223333333333444444444555
123456789012345678901234567890123456789012345678901
551 1 701 0.0
```
Card Type 22. Configuration Matrix Cards.

This card is used to identify the different groups in the systems being evaluated. The format for these cards is as follows:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>I4</td>
<td>NB0</td>
<td>The number of members in the group defined on this card that are required to be operational and in an up state.</td>
</tr>
<tr>
<td>5-8</td>
<td>I4</td>
<td>IB(1)</td>
<td>The group number assigned to the group of members defined on this card. It may vary from 501 to 1000.</td>
</tr>
<tr>
<td>9-12</td>
<td>I4</td>
<td>IB(2)</td>
<td>The numbers of the equipment and groups which make up the group defined on this card.</td>
</tr>
<tr>
<td>13-16</td>
<td>I4</td>
<td>IB(3)</td>
<td>The max number of members in a group is unlimited; however, if there are more than 7, a continuation card is required, which is of the same format.</td>
</tr>
<tr>
<td>17-20</td>
<td>I4</td>
<td>IB(4)</td>
<td>The number required and master group number must be identical on all continuation cards.</td>
</tr>
<tr>
<td>21-24</td>
<td>I4</td>
<td>IB(5)</td>
<td></td>
</tr>
<tr>
<td>25-28</td>
<td>I4</td>
<td>IB(6)</td>
<td></td>
</tr>
<tr>
<td>29-32</td>
<td>I4</td>
<td>IB(7)</td>
<td></td>
</tr>
<tr>
<td>33-36</td>
<td>I4</td>
<td>IB(8)</td>
<td></td>
</tr>
</tbody>
</table>

An example of the Configuration Matrix Cards used for the system in Figure 5.12 is:

Card Columns:

```
111111111222222233333333444444444
12345678901234567890123456789012345678901
1 501 2 3
2 502 5 6
3 503 7 8
4 501 502 601
```
Card Type 23: Equipment Operating Rule Cards.

Operating rules can be specified which will turn selected equipments on and off in predetermined situations. These operating rules were not utilized during this research. All equipments ran all of the time except when they were inoperable. A detailed discussion of the use of this option can be found in Reference 4, chapter 3.

Card Type 24: Blank Card

Card Type 25: Optional Output Card.

Optional output tables can be selected by using this card as shown below.

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>A4</td>
<td>SPRS</td>
<td></td>
<td>Place any alphanumeric (ie. &quot;SPRS&quot;) in this field if a table of spares usage is desired.</td>
</tr>
<tr>
<td>5-8</td>
<td>A4</td>
<td>APPL</td>
<td></td>
<td>Place any alphanumeric (ie. &quot;APPL&quot;) in this field if a summary table of equipment that caused mission failures and system downtimes is desired.</td>
</tr>
<tr>
<td>9-12</td>
<td>A4</td>
<td>GHMA</td>
<td></td>
<td>Place any alphanumeric (ie. &quot;GHMA&quot;) in this field if the gamma distribution output is desired.</td>
</tr>
<tr>
<td>13-16</td>
<td>A4</td>
<td>DEMO</td>
<td></td>
<td>Place any alphanumeric (ie. &quot;DEMO&quot;) in this field if a sequential probability ratio test plan for the system being analyzed is desired. If this option is exercised, an additional card, 26, is required.</td>
</tr>
</tbody>
</table>
Card Type 26: DEMO Information Card.

This card must be included if DEMO is specified on the Optional Output Card. A detailed discussion of the DEMO Option is provided in Reference 4, chapter 3. The format for this card is as follows:

<table>
<thead>
<tr>
<th>Columns</th>
<th>Format</th>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-4</td>
<td>F4.0</td>
<td>A</td>
<td>Producer Risk.</td>
</tr>
<tr>
<td>5-8</td>
<td>F4.0</td>
<td>B</td>
<td>Consumer Risk.</td>
</tr>
<tr>
<td>9-12</td>
<td>F4.0</td>
<td>R</td>
<td>Discrimination Ratio.</td>
</tr>
</tbody>
</table>

The following are optional inputs.

- 13-16 F4.0 HAD I-axis accept intercept (Delta)
- 17-20 F4.0 HRD I-axis reject intercept (Delta)
- 21-24 F4.0 YD Truncation line accept (Delta)
- 25-28 F4.0 SLD Slope (Delta)
- 29-32 I4 KD Truncation line reject (Delta)
- 33-36 I4 ITIME Number of sets
- 37-40 I4 ITER Number of simulations per set
- 41-44 I4 N Random number initializer

The total input required for the system in Figure B.12 is shown in Figure B.13.
Figure B.13 Complete TIGER Program Input Example
MAIN PROGRAM

COMMON /ALPHA/DNT2, ENDPHA, ICRI, IPP, IPR, INUM, IOPT, JBB, KEQ, KKK, KZI
1, KK1, KS1, LL, LLLA, NEQ, NPH, NTYPE, NUM, REDAD2, REDAD1 (100), RELP, RED2
2, RELPY, REPOL, STPHAS, TP, T1, TCUR, TT3, UP3, IPPEOP, T3, TIME, T3SUM
COMMON/BEUA/WRO(6, 300), IB(6, 300, 8), WLINE(6)
COMMON/EXTRA/ KS(20), LSU(31)
COMMON/MXEOU(500), KEQU(500), ETIME(1000), XMTBP(200), XMTTR(200)
COMMON/MXH/NSS(16), IFLAG(6), TITLE(6, 31), SSTIME(6, 31, 2), ISS(6, 31)
COMMON/SIQ/INOABT(100), INMI(100), IARP1(100), TT2(100), UP2(100)
1, IAUP1(100)
COMMON/TIP/EX(2, 200), ISPARF(6, 200), IUSED(3, 200), ITUSED(3, 200)
COMMON/MXMAXEQ, MAUSP, MAXIB, MAUSST
COMMON/XXMTRA, VAR, RELGA(100), TIMA(100), XXT(200), IXT, ISEED
COMMON/TABTB/ XTAB(1000), RDT
COMMON/TIGAP/ UP4, INUM, BPRIN, AVA, XPCAP, RUNID(19), TYCOON(500)
*, COUNTB(500), ITCOM
COMMON/DONE/DONE(3)
C ORELLY ADD
C DELETING THEIR PRINTOUTS WITH CHHERE
COMMON /ISPARF/IFLAG, BUDGET, COST(201)
COMMON/KSPARE/ JTME, TOTSPR, COMB(9999), COMBA(9999), SER(100)
COMMON/GEALG/NOSPRS
INTEGER TOTSPR, NOSPR, COMB, COMBA, SER
C ORELLY STOP
DATA BLNK/4H
/
C MAXNUM=1000
MAXNPH=6
MAXSTD=50
MAXNEQ=500
MAXTP=200
MAXIB=300
MAXSS=31
MAXSEU=100
CALL OVFLW
OREILLY ADDS

I=0
NOSPRS=0
1 I=I+1
READ 5,9,COMB(I),COMBA(I),SER(I)
IF(200-COMB(I)) 5,5,4
5 IF(COMB(I)-1) 10,3,3
4 NOSPRS=NOSPRS+1
6 NOSPRS=NOSPRS+1
GO TO 1
9 FORMAT(14,14,14)
10 READ 5,13,NTOTA,XFLAG,BUDGET
11 FORMAT(14,2,6,0,0)
READ 5,13,COST(I),I=1,NTOTA
13 FORMAT(8.2)

OREILLY STOPS
READ 5,19,JCC,(RUNID(I),I=1,19)
19 FORMAT(14,19A4)
WRITE (6,220) JCC
DO 1230 JC=1,JCC
20 WRITE (6,30),(RUNID(I),I=1,19)
30 FORMAT(14,30,(19A4/)20)
WRITE (6,40)
WRITE (6,50)
WRITE (6,55)
WRITE (6,36)
40 FORMAT(11,50H +++++++++++++++++++++ TIGER ++++++++++++++++++)
50 FORMAT(/11,50H++ NAVSEC 6112 LUEJEN*MANDEL+VAIL+ALLEY+BROWN ++)
55 FORMAT(/11,50H++NPS IBM/360 VERSION LT. J. LEATHER THESSES 9/80++)
56 FORMAT(/11,50H++AS AMENDED BY LCDR. P.J. O'REILLY THESSES 12/81++)
BAPHN=0,0
DO 70 I=1,MAXNEQ
60 COUNTB(I)=0.0
TICON(I)=0.0
KEOU(I)=0
70 ETIME(I)=100000.
NUM=0
IPF=0
TFR=0
UP4=0.0
T1 = 0.0  
T2SUM = 0.0  
SUMX = 0.0  
SUMX2 = 0.0  
DO 80 I = 1, 100  
80 TMA(I) = 0.0  
DO 90 I = 1, 3  
90 T1UED(I, 1) = 0  
DO 100 I = 1, MAXSEQ  
100 T2(I) = 0.0  
UP2(I) = 0.0  
INUP1(I) = 0  
INUP2(I) = 0  
REDAD1(I) = 0.0  
INMI(I) = 0  
100 INOABT(I) = 0  
INUP = 0  
ITTUM = 0  
IF (JC = 1) 110, 110, 140  
110 READ (5, 120) NMAX, NOPT, PL, XK, ISEED, NPH  
120 FORMAT (2I4, 2F4.0, 2I4)  
130 FORMAT (IX216, 2FX4.2, 2FX5.2, 2XI6, 2XI4)  
140 CONTINUE  
160 WRITE (6, 170) ISEED  
170 FORMAT (/1X, 15BRAND seed is , I4)  
180 IF (NMAX-MAXRUN) 190, 190, 180  
190 NMAX = 1000  
NOPT = 1000  
190 DO 200 I = 1, NMAX  
200 X1ABT(I) = 100000.0  
WRITE (6, 130) NMAX, NOPT, PL, XK, ISEED, NPH  
IF (MAXPH-MPH) 210, 210, 240  
210 INUP = 50  
220 FORMAT (/1X, 5HJCC = , 4I10)  
230 DO 250 I = 1, 191, 10  
READ (5, 240) IIT(I), JXT(I), J = 1, 9  
IF (IIT(I)) 260, 260, 250  
240 FORMAT (5F2.0, F8.0)  
250 CONTINUE  
260 WRITE (6, 270)  
270 FORMAT (1H1, 10X4O NPHASE SEQUENCE TYPE DURATION CUM TIME)  
IK = 1  
IK2 = 2*IK  
IK3 = IK2 - 1  
IIT = IIT(IK3)  
TIMA(I) = IIT(2)  
WRITE (6, 280) IK, IIT, IIT(IK2), TIMA(IK)
280 FORMAT (19I4,2XI4,2XP8.2,2XP8.2)
DO 300 IK=1,100
IK2=2*IK
IK3=IK2-1
IF (IKT(IK2)) 290, 310, 290
290 TIMA(IK)=TIMA(IK-1)+XTT(IK2)
IXT=IXT(IK3)
WRITE (6,280) IK,IXT,XTT(IK2),TIMA(IK)
300 CONTINUE
310 CONTINUE
IF (IC-1) 320,320,330
320 CALL PACK
C
330 CONTINUE
JBB=1
BELFY=1.0
BELFY=1.0
UP3=0.0
TP3=0.0
READ2=0.0
DO 340 I=1,MAXSS
340 ISW(I)=1
ICBI=0
DNT2=0.0
350 STPHAS=0
IT=0.0
C
360 KAB=NUM+1
WRITE (6,370) KAB
C
CHEE WRITE (6,370) KAB
370 FORMAT (1X,16HSTART OF MISSION,I5,20H*******************************)
380 KK=0
390 I=1
400 LL=IXT(I)
IF (LL) 450,450,410
410 ENDPHA=STPHAS+XTT(I+1)
I=I+2
CALL RUN
IX=NUM+1
IF (ITABT(I)) 420,420,440
CHEE ALSO CHANGE LABEL 420 BELOW
C
420 WRITE (6,430)
430 FORMAT (1X4HTHE ABORT TIME IS ZERO,CHECK THE INPUT DATA.)
420 GO TO 1240
440 STPHAS=ENDPHA
C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
C ADDRESSES 669 AND 671 ADDED FOR THIS PRINT DELETION ONLY
IF (NUM-1000.) 671,669,671
669 WRITE (6,670) AVA
670 FORMAT (1X28HTHE AVERAGE AVAILABILITY IS ,F8.4)
671 XIAUP=IAUP
AVAINS=XIAUP/XNUM
C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
C ADDRESSES 679 AND 681 ADDED FOR THIS PRINT DELETION ONLY
IF (NUM-1000.) 681,679,681
679 WRITE (6,680) AVAINS
680 FORMAT (1X28HTHE INSTANT AVAILABILITY IS ,F8.4)
681 IDWN=XNUM-1TCUH
IF (IDWN) 690,690,700
690 XMTBA=2.0*SUMX
XLCLA=0.434*SUMX
VAR=(0.5*SUMX)**2
GO TO 710
700 XMTBA=SUMX/IDWN
VAR=(SUMX2/XNUM)-(SUMX/XNUM)**2
CORR=(SUMX**2/(1/IDWN-1/XNUM))**2
VAR=VAR+CORR
XLCLA=XMTBA-(1.28*SORT(VAR))
C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
C ADDRESSES 741 ADDED FOR THIS PRINT DELETION ONLY
IF (NUM-1000.) 741,710,741
710 WRITE (6,720) XMTBA
720 FORMAT (1X28HTHE MEAN TIME BETWEEN MISSION FAILURES IS,F20.1)
WRITE (6,730) XLCLA
730 FORMAT (1X28HTHE LCL,90, MTBMF IS ,F20.1)
WRITE (6,740) VAR
740 FORMAT (1X28HTHE MTBMF VARIANCE IS ,F20.1)
741 XIFF=IFP
XIFF=IFP
IF (IFF) 760,750,760
750 XMTU=2.0*UP4
IMDT=0
GO TO 790
760 XMTU=UP4/XIFF
IF (IPR) 780,770,780
770 IMDT=(T3-UP4-T3SUM)/XIFF
GO TO 790
780 IMDT=(T3-UP4-T3SUM)/XIFF
C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
IF (NUM-1000.) 830,790,830
790 WRITE (6,810) XMTU
800 WRITE (6,820) IMDT
810 FORMAT (1X18HTHE SYSTEM MUT IS ,F20.1)
820 FORMAT (1X18H THE SYSTEM MDT IS, F20.3)
830 IF (IISPAP-PL) 840, 840, 920
840 IF (IHP=NUM) 870, 870, 880
850 WRITE (6, 860)
860 FORMAT (1X14H ANOTHER SET OF 3X 50, 200 MISSIONS WILL BE RUN, 43H TO OBTAIN REQUIRED STATISTICAL CONFIDENCE.)
     GO TO 330
870 WRITE (6, 880)
880 FORMAT (1X52H SIMULATION COMPLETE - OPTIMUM NUMBER MISSIIONS WERE RUN)
     IF (PL.EQ.1.) GO TO 910
890 WRITE (6, 900)
900 FORMAT (1X33H WEAPON SYSTEM FAILS REQUIREMENTS.)
910 GO TO 1010
920 IF (IHP=NUM) 930, 930, 960
930 WRITE (6, 940)
940 FORMAT (1X52H SIM COMPLETE - PREDEFINED MAX NUMBER MISSIIONS WERE RUN)
950 IF (IPLCL-PL) 980, 980, 990
960 IF (IPLCL-PL) 980, 980, 970
970 WRITE (6, 980)
980 FORMAT (1X22H SIMULATION COMPLETE - )
     IF (PL.EQ.1.) GO TO 1010
990 WRITE (6, 1000)
1000 FORMAT (1X33H WEAPON SYSTEM MEETS REQUIREMENTS.)
1010 CONTINUE
1020 IF (JC-1) 1020, 1020, 1040
1020 READ (15, 1030) SPRS, APL, GMNA, DMNO
1030 FORMAT (4A4)
1040 IF (SPRS.EQ.100) GO TO 1190
1050 IDIFF=0
1050 TAPM-0.0
1050 TACMMH-0.0
1060 WRITE (6, 1060)
1060 FORMAT (1H,4X53H EQUIP FAILURES AND CORRECTIVE MAINTENANCE (CM), SUM 1MBR.Y. 8X71HEQUIP, NO. TYPE NO. TOTAL EQUIP. AVG. NO. FAILURES/ A 2V.G. CH MANHOURS/3X18H FAILURES, 7X11HPER MISSION, 5X11HPER MISSION/)
DO 1090 I=1, NQX
1090 IF (IMTR(I).NEQ.9999) GO TO 1090
1090 IF (KEQ(I)) 1090, 1090, 1070
1070 APF=KEQ(I) 
1070 KEQ=ABS(KEQ(I))
1070 TACMMH=APF*ABS(KEQ(I))
1070 WRITE (6, 1080) I, I, KEQ(I), APF, TACMMH
1080 FORMAT (10X14, 6X14, 6X10, 6X10.3, 6X10.3)
1080 IDIFF=IDIFF+KEQ(I)
1080 TAPM=TAPM+APF
1080 TACMMH=TACMMH+ACMMH
1090 CONTINUE
1090 WRITE (6, 1100) IDIFF, TAPM, TACMMH
1100 FORMAT (3IX10H---------,6X10H---------,6X10H---------)/31X10,6X
1P10.36XF10.3)
1110 CONTINUE
WRITE (6,1120)
1120 FORMAT (1EH1,N1X4H AVERAGE NUMBER OF SPARES USED PER MISSION)
WRITE (6,1130)
1130 FORMAT (/4X6HSPARES,7X4HSHIP,18X6HTENDER,16X4HBASE)
WRITE (6,1140)
1140 FORMAT (8X4HTYPE,4X3(5HSTOCK,3X4HUSED,10X))
DO 1170 J=1,NTYPE
ALDONE=0.0
DO 1150 I=1,3
DONE(I)=IUSED(I,J)/INUM
ALDONE=ALDONE+DONE(I)
1150 CONTINUE
IF (ALDONE) 1155,1170,1155
1155 WRITE (6,1160) J,1ISPARSE(I,J),DONE(I),I=1,3
1160 FORMAT (6X4,14(15,F7.2,:'10'))
1170 CONTINUE
1180 CONTINUE
1190 IF (APPLE,30, BLNK) GO TO 1210
1200 BAPEND=1.0
CALL APPLE
1210 CONTINUE
1220 CONTINUE
1230 CONTINUE
1240 STOP
END

SUBROUTINE RUN
COMMON /MAX/MAXNEQ,MAXTYP,MAXIB,MAXSTD
COMMON /ALPHA/DN,EMDPS,IC,IFF,IPR,INUM,IOPT,JBB,KEQ,KKK,KZZ
1,KK1,KST,ILL,LLLST,NEQ,NP,NV,NVTP,NUM,BEDAD2,BEDAD1(100),HELP,BRED2
2,BELAY,BESOL,STPHA,TP,T1,ICUM,TP3,IPFEP,T3,TIME,T3SUM
COMMON/BETA/NE0(6,500),FB(6,300,8),Nligne(6)
COMMON/EXTRA/IF(20),IS(31)
COMMON/W,IEQ(500),KEQ(500),ETIME(1000),XMTBF(200),XMTTR(200)
COMMON/WTP/HSSH(6),IPLAG(6),TITLE(6,31),STTIME(6,31,2),ISS(6,31)
COMMON/SQP/INDAB(100),INH(100),ISUP1(100),ISUP2(100)
1,ISUP3(100)
COMMON/TYP/EX(2,200),1SPARE(3,200),USRD(3,200),ITUSED(3,200)
COMMON/GAMMA/INTB,VAR,RELC(100),TIMA(100),XMT(200),ITF,ISEED
COMMON/DELTAB/XTABF(1000),RDT
COMMON/DXX/KK2
COMMON/XX/XX
COMON / VDC / VDC (50, 6), YU (200), VMTT (200, 6), TAD2
COMON / STAV / ISST (60, 40, 6)
COMON / RUN4 / VTRAP, DELT, ISSA (31), ISSC
COMON / XSPARE / XFLAG, BUDGET, COST (201)

C
TDEP=0.0
TP=STPHAS
KAA=NUM+1
XKAA=KAA
MM=ISS (LL)
M=M*1
ITEMP=0
ITEMP2=0
10 DO 20 I=1,3
20 CONTINUE
DO 30 J=1,NTYPE
IUSED (I, J) = 0
30 CONTINUE
DO 40 I = 1, NEQ
40 CONTINUE
50 DO 120 ILB=1, NEQ
        KEQ=ILB
        ETIME (KEQ) = 100000, 100001, 100002, 100003
55 IF (ETIME (KEQ) < 100000) 55, 120, 55
60 IF (ITEM (LL)) 120, 70, 120
C
70 ETIME (KEQ) = STPHAS
       IABC=IABS (IEQU (KEQ))
       IF (YMTT (IABC)) 80, 90, 100
80 XXX=VMTT (IABC, LL)
       IF (XXX-99999.) 120, 90, 120
90 ETIME (KEQ) = -99999.
       GO TO 120
100 XXX=VMTT (IABC)
110 CALL TTE
120 CONTINUE
C
DO 140 ILB=1, NEQ
        KEQ=ILB
        IEQU (KEQ) = IABS (IEQU (KEQ))
        IF (ETIME (KEQ) < 100000.) 130, 140, 130
130 IEQU (KEQ) = -IABS (IEQU (KEQ))
140 CONTINUE
150 CONTINUE
C
KKK2=KKK
```
K=NLNE(LL)
DO 250 J=1,K
DO 250 I=1,K
KEQ=IABS(IE (LL, I, J))
IF (KEQ MAX NEQ) 151, 151, 250
151 IF (KEQ) 250, 250, 155
155 IF (ETIME(KEQ) - 100.000, 000I) 160, 250, 160
160 IEQU(KEQ) = IABS(IEQU(KEQ))
TABC = IEQU(KEQ)
IF (IWTET(TABC)) 170, 170, 180
170 IF (WMTET(TABC, LL) = 9999) 180, 190, 180
180 CONTINUE
IF (IFLAG(LL) = 1) 210, 190, 210
190 IF (ETIME(KEQ)) 200, 210, 210
200 ETIME(KEQ) = ETIME(KEQ) - (EMDPA-STPHAS)
210 IF (ETIME(KEQ) = 100.0000) 220, 240, 220
220 IF (ABS(ETIME(KEQ)) = STPHAS) 240, 230, 230
230 IF (STPHAS) 250, 240, 250
240 ETIME(KEQ) = STPHAS
TABC = IABS(IEQU(KEQ))
XIX = INTBF(TABC)
CALL TTE
250 CONTINUE
KKK = 1
C
DO 330 ILB = 1, NEQ
KEQ = ILB
IF (ETIME(KEQ)) 325, 325, 325
325 IF (IEQU(KEQ)) 260, 260, 320
260 IEQU(KEQ) = IABS(IEQU(KEQ))
TABC = IEQU(KEQ)
IF (IWTET(TABC)) 270, 270, 280
270 IF (WMTET(TABC, LL) = 9999) 280, 290, 280
280 CONTINUE
IF (IFLAG(LL) = 1) 310, 290, 310
290 IF (ETIME(KEQ)) 300, 320, 320
300 ETIME(KEQ) = ETIME(KEQ) - (EMDPA-STPHAS)
GO TO 330
C
310 IF (ETIME(KEQ)) 331, 320, 320
320 ETIME(KEQ) = 100000
IEQU(KEQ) = IABS(IEQU(KEQ))
GO TO 330
331 IEQU(KEQ) = IABS(IEQU(KEQ))
330 CONTINUE
C
CALL STATUS
CALL STDBY
```
C
CALL STATUS
IF (I$W(N)) 350, 350, 340
340 IAUPI(JBB)=IAUPI(JBB)+1
350 XIAUPI=IAUPI(JBB)
IAV=IAUPI/JAA
C
TIME=STPHAS
DWT=0.0
DO 360 KSS=1,N
360 SSTIME(LL,KSS,1)=0.0
C
370 TP=TIME
CALL STNDBY
380 IF (KS(6)) 390,440,390
390 WRITE (6,430) TP
DO 410 J=1,NEQ
400 IEQ=IABS(IEQ(J))
WRITE (6,420) J,IEQ,ETIME(J)
410 CONTINUE
420 FORMAT (1X5.1X5.5XP22.4)
430 FORMAT (1XP12.4)
440 CALL EVENT
TIME=ABS(ETIME(KEQ))
IF (KS(5)) 450,470,450
450 WRITE (6,460) KEQ,ETIME(KEQ),KAA
460 FORMAT (10X5HEQUIP,15,F12.4,5X7MISSION,110)
470 DLT=TIME-TP
CALL STATUS
C
480 DO 510 KSS=1,NX
IF (I$W(KSS)) 490,490,500
490 SSTIME(LL,KSS,1)=SSTIME(LL,KSS,1)+DELT
GO TO 510
500 SSTIME(LL,KSS,1)=0.0
510 CONTINUE
IF (I$W(N)) 520,520,530
520 SSTIME(LL,N,1)=SSTIME(LL,N,1)+DELT
T3=T3+DELT
IF (TIME-ENDPHA) 522,522,521
521 T3=T3+ENDPHA-TP-DELT
522 RDT=RDT+DELT
GO TO 550
530 T3=0.0
RDT=0.0
IF (SSTIME(LL,N,1)) 1140,550,540
540 T1=SSTIME(LL,N,1)
SSTIME(LL,N,1) = 0.0  
550 CONTINUE  
C
IF (SSTIME(LL,N,1))  570, 560, 570  
560 IF (T1)  620, 620, 580  
570 IF (T1)  620, 610, 620  
580 IF = IF + 1  
590 IFR = IFR + 1  
600 T1 = 0.0  
610 GO TO 620  
620 CONTINUE  
C
IF (ICRI)  640, 640, 660  
640 ISSC = 1  
645 ICRI = 0  
650 IF (SSTIME(LL,N,1) - SSTIME(LL,N,2))  650, 650, 960  
655 ISSC = 0  
660 DO 655 KSS = 1, NY  
670 IF (SSTIME(LL,KSS,1) - SSTIME(LL,KSS,2))  655, 655, 652  
680 ISSC = ISSC + 1  
690 ISSA (ISSC) = KSS  
700 CONTINUE  
710 IF (ISSC)  660, 660, 962  
720 CONTINUE  
C
IF (TIME - ENDPHA)  670, 670, 1140  
675 IF (ISW(N))  680, 680, 730  
680 CALL APPLE  
700 IF (ETIME(KEO))  810, 810, 740  
710 IABC = IABS (IEQU (KEO))  
720 IFLAG (LL - 1)  750, 760, 750  
730 CALL LRND (ISeed,RN)  1, 16807, 0  
740 IF (RN - REPOL)  770, 770, 800  
750 ETIME (KEO) = -99999  
760 GO TO 830  
770 IF (IATTR(IABC))  780, 780, 790  
780 IIX = IATTR (IABC,LL)  
790 IIX = IATTR (IABC)  
800 ETIME (KEO) = -10000 1.001  
810 GO TO 830  
820 GO TO 820  
830 IF (IABC)  840, 840, 850  
840 IABC = IABS (IEQU (KEO))
XY=1 MTBF (I ABC)
820 IF IFQV (KEQ) 811, 821, 821
831 IFQ (KEQ) =IABS (IFQV (KEQ))
ETIME (KEQ) = 100000.
GO TO 830
821 CALL TTE
830 IF (ETIME (KEQ)) 840, 1150, 870
C
840 KEQV (KEQ) =KEQV (KEQ) + 1
IF (ISW (N)) 850, 850, 370
850 DNT1 = DNT1 + DELT
IF (ICRI) 860, 370, 860
860 READD1 (JBB) = READD1 (JBB) + DELT
GO TO 370
C
870 CONTINUE
IF (ISW (N)) 880, 880, 370
860 DNT1 = DNT1 + DELT
IF (ICRI) 890, 900, 890
890 READD1 (JBB) = READD1 (JBB) + DELT
900 TDOW-Time = SSTIME (LL, N, 1)
TTEMP = SSTIME (LL, N, 1)
IF (KS (13)) 370, 370, 910
CHERE ALSO CHANGE LABEL 910
C
910 WRITE (6, 920) LL, TDOW, TTEMP, KAA
920 FORMAT (13H DURING PHASE, 16, 2OH SYSTEM WENT DOWN AT ,F14.4, 13H DOWN
TIME IS ,F14.4, 3X7MISSION, 16)
910 GO TO 370
C
930 ICRI=5
TABORT = TIME - (RDT-TAD2)
IF (TABORT-ENCPHA) 940, 645, 645
940 IF (ITABT (KAA) - 100000.) 660, 950, 660
950 ITEMP=1
ITEMP2=1
CHERE WRITE (6, 1010) LL, JBB, KAA, TABORT, TITLE (LL, N), TAD2
GO TO 1020
960 ICRI=4
GO TO 964
962 ICRI=2
964 TABORT = TIME - (SSTIME (LL, ISSA (1), 1) - SSTIME (LL, ISSA (1), 2))
970 IF (TABORT-ENCPHA) 990, 980, 980
980 IF (ICRI2) 650, 985, 650
985 ICRI=0
GO TO 660
990 IF (ITABT (KAA) - 100000.) 660, 1000, 660
1000 ITEMP=1
ITEMP2=1
CHERE DO 1005 I=1,ISSC
C100  WRITE (6,100) JBB,KAA,TABORT,TITLE(LL,ISSA(I))
C1009 FORMAT (1X,5H PHASE,12,1X,3HSEQ,13,4X7HMISSION,16,4X15HABORTED AT
1TIME,F10.4) 10H BECAUSE ,A4,35H EXCEEDED PHASE ALLOWABLE DOWNTIME
2 TIME,2F10.3,5H HRS.)
1010 FORMAT (1X9H PHASE,12,1X3HSEQ,13,4X7HMISSION,16,4X15HABORTED AT
1TIME,F10.4) 10H BECAUSE ,A4,37H EXCEEDED MISSION ALLOWABLE DOWNT
C1090 WRITE (6,110) I,ETIME(I)
C1100 FORMAT (1X7HSHEQIPMENT,15,24H DOWN IT WILL COME UP AT,F16.4)
1110 CONTINUE
1120 CALL APPLE
ITEMP2=0
1130 GO TO 660
C
1140 CONTINUE
1150 CONTINUE
1160 TDEOP=ENDPHA-TP
1170 CONTINUE
1180 IF (KS(3)) 1210,1210,1190
1190 IF (TDEOP) 1210,1210,1190
CHERE PREVIOUS LINE WAS 1190,1190,1190
C1190 WRITE (6,1200) LL,TDEOP,KAA
1200 FORMAT (1X27HSYSTEM DOWN AT END OF PHASE,16,1JH FOR DURATION,F10.4
1161HMISSION,16)
1210 CONTINUE
1220 DNT=2+DNT1+TDEOP
1230 DNT=DNT+TDEOP-DELT
1240 CALL APPLE
1270 CONTINUE
1280 IF (ICRT) 1280,1290,1280
1290 REDAD1(JBB)=REDAD1(JBB)+TDEOP
1300 IF (DNT2) 1310,1330,1310
1320 REDAD1(JBB)=REDAD1(JBB)+TDEOP
1325 WRITE (6,1325) LL,KAA,DNT2
1320 FORMAT (15,9H PHASE, I5, 1X, 29H TOTAL SYS DOWNTIME IN MISSION, I5, 1X, 3H WAS
1 P12, 4.4H HRS)
1330 CONTINUE
C
1340 IF (XCRT1) 1350, 1350, 1340
1350 IF (ITEMP) 1360, 1360, 1350
1350 ICUR=1-ITEMP
1350 INOABT(JBB) = INOABT(JBB)+1-ITEMP
1360 CONTINUE
1360 XNO=INOABT(JBB)
1360 XNH=INH(JBB)
1370 RELY=XNO/XNH
GO TO 1390
1380 RELY=0.0
1390 RELP=RELP + RELY
1400 TT2(JBB) = TT2(JBB) + TT1
1400 UP1=TT1-DNT1
1400 UP2(JBB)=UP2(JBB)+UP1
1400 IApr1=IApr1(JBB)+1
1410 XIAUPP=IAUPP(JBB)
1410 XAV=XIAUPP/XAA
1500 IF (KAA=INH) 1570, 1420, 1570
CHERE1
C 1420 WRITE (6, 1430) XAVI
1430 FORMAT (9H47X20H INSTANT AVAILABILITY, 5X, 2X4H IS, F6.4)
CHERE1
C 1440 WRITE (6, 1450) LL, JBB, RELY, LL, RELP
1450 FORMAT (9H47X17H RELIABILITY PHASE, I3, 1H, I3, 5H, IS, F6.4, 3X, 25H RELIABILI
1460 1L UP TO PHASE, I2, 4H IS, F6.4)
CHERE1 1.20 IN BELOW LINE SHOULD BE NEXT TO ABOVE WRITE(6, 1430)
1420 RELPH(JBB) = RELP
1420 AENDT1=0.0
1420 AENDT2=0.0
1460 DO 1520 I=1, KAA
1470 IF (IXABT(I)=1000000) 1470, 1520, 1520
1470 IF (IXABT(I)=-TIMA(JBB)) 1480, 1520, 1520
1480 AENDT2=AENDT2+TIMA(JBB)-XTABT(I)
1490 JBB1=JBB-1
1490 IF (JBB1) 1500, 1500, 1490
1490 IF (TIMA(JBB1)-XTABT(I)) 1500, 1500, 1510
1500 AENDT1=AENDT1+TIMA(JBB)-TIMA(JBB1)
GO TO 1520
1510 CONTINUE
1520 CONTINUE

SUBROUTINE PACK
COMMON /ALPHA/DNT 2, ENDPHA, ICRI, IFF, IPB, INUM, IOPT, JBB, KEQ, KKK, KZ2
1, KK1, KS1, LLLAST, NER, NHR, NTYPE, NODE, REDAD2, REDAD1(100), RELP, RED2
2, RELPY, REPOL, STHAS, TP, TI, ICUM, TT3, UP3, IPFEOP, T3, TIME, TSUM
COMMON/BETA/NRO(6,300), IB(6,300,6), KLNE(6)
COMMON/EXTRA/ KS(200), ESW(31)
COMMON /ETEQ(500), REQU(500), ETIME(1000), XMTBF(200), XMTTR(200)
COMMON/NPR/ ISS(6), IFLAG(6), TITLE(6,31), STIME(6,31), DSS(6,31)
COMMON/TYP/EX(2,200), ISPARE(3,200), IUSE(3,200), ITUSE(3,200)
COMMON/MAI/MAINEQ, MAXTYP, MAXSTD
COMMON/VDC/VDC(50,6), IUT(200), VMTR(200,6), TAD2
COMMON /PACKAP/ JNUM(6,500), ISYS(6), F(200,4)
COMMON/STAN/STB(60,10,6)
COMMON/CSPAR/ SPR1, SPR2, SPR3, SPR4, SPR5, SPR6, SPR7, SPR8, SPR9
1, SPR10, SPR11, SPR12, SPR13, SPR14, ITMPOP(200)
COMMON/ISPAR/IXFLAG, BUDGET, COST(201)
DIMENSION LOAD(19)
DIMENSION DUM(4)
DIMENSION TVAL(10)
DATA IBLANK/4H/
C
READ (5,10) KOPT, (KS(I), I=1,13)
WRITE (6,20) KOPT, (KS(I), I=1,13)
10 FORMAT (20I4)
20 FORMAT (18H1, 110, 5X19I4)
   C
   READ (5, 10) (IFLAG(I), I=1,NPH)
   WRITE (6, 30) (IFLAG(I), I=1,NPH)
30 FORMAT (10I4)
   C
   READ (5, 40) REPOL, TAD2, XM, XM1
40 FORMAT (1P8.0, FP8.0, 2P4.0)
50 FORMAT (20F4.0)
   IF (XM) 35, 35, 55
   IF (XM1) 36, 36, 56
   IF (XM1) 1
60 FORMAT (1X, 4F10.2)
   GO TO (70, 90, 100, 120, 130), KOPT
   C
70 KS(1) = 1
80 KS(4) = 0
   KS(3) = 0
   KS(5) = 1
   KS(5) = 0
   KS(10) = 0
90 KS(1) = 1
   KS(6) = 0
   KS(10) = 0
GO TO 130
100 KS(1) = 1
   KS(6) = 1
   KS(10) = 1
   KS(4) = 1
   KS(12) = 1
110 KS(2) = 1
   KS(3) = 1
   KS(8) = 1
   KS(5) = 1
   KS(7) = 0
   KS(9) = 0
   KS(2) = 1
GO TO 130
120 KS(1) = 0
KS(4) = 0
GO TO 80

C 130 NEQ = 0
DO 140 I = 1, MAXNEQ
 ISEU(I) = 100000.
 ISEU(I) = 0
140 CONTINUE
DO 155 J = 1, 6
DO 150 I = 1, MAXTYP
 XMTBF(I) = 0.0
 VMTR(I, J) = 0.0
150 XMTTR(I) = 0.0
155 CONTINUE

C 160 WRITE (6, 170)
170 FORMAT (/1'H TYPE NAME, 18X 'HMTBF, 5X 'HMTTR, 7X 'HDC, 8X 'HADT1, 4X 'HADT
121)
180 FORMAT (5, 190) I, (DUM(J), J = 1, 4), X, Y, U, V, W, IDUM
190 IF (I) 200, 490, 200
200 IF (I = MAXTYP) 220, 220, 210
210 WRITE (6, 440)
GO TO 180
220 DO 230 J = 1, 4
230 IF (J) DUM(I, J)
 DUM(I) = DUM(I, J)
240 READ (5, 450) IU(I), (VDC(IU, ILL, ILL = 1, NPH)
250 IF (Y) 260, 280, 280
260 READ (5, 505) VMTR(I, J), J = 1, NPH
270 IF (I) 280, 490, 280
280 EX(I, J) = V
 EX(2, I) = W
 IF (KS(I)) 310, 310, 290
290 WRITE (6, 300) I, (F(I, J), J = 1, 4), X, Y, U, V, W
300 FORMAT (1'I4, 2'F4.4, 2'X', 10.1, 2'X', 10.2, 4'F4.2 (F8.1)
310 IF (IU(I)) 380, 380, 320
320 IF (KS(I)) 340, 340, 330
330 WRITE (6, 460) (VDC(IU, ILL), ILL = 1, NPH)
340 DO 370 ILL = 1, NPH
350 IF (VDC(IU, ILL)) 360, 360, 350
360 VDC(IU, ILL) = (X = .0001) * XM
 GO TO 370
370 CONTINUE
380 IF (KS(I)) 410, 410, 390
390 IF (Y) 400, 410, 410
400 WRITE (6, 470) (MTTR(I, J), J=1, NPH)
410 IF (MTTR(I)) 420, 430, 420
420 WRITE (6, 480)
430 GO TO 1060
435 IF (U) 435, 435, 433
433 IF (U) = IM* (I/0)
435 MTTR(I) = IM* (I/0)
440 GO TO 130
440 FORMAT (9X39HEQUIP TYPES HAVE EXCEEDED MAX ALLOWABLE)
450 FORMAT (I4, 19(F4, 0))
460 FORMAT (14X16HVARY DUTY CYCLE, 4F10, 3)
470 FORMAT (14X16HVARIBLE MTTR, 4F10, 3)
480 FORMAT (14XHTYPE, I5, 1X13HDEFINED TWICE)

C
490 WRITE (6, 500)
500 FORMAT (/1X15HTYPE EQUIPMENT)
510 READ (5, 10) NTYPE, (LOAD(I), I=1, 19)
520 IF (LOAD(I)) 520, 650, 520
530 DO 620 I=1, 19
530 IF (LOAD(I)) 530, 620, 530
540 IF (IBM=LOAD(I)) 560, 560, 540
540 IF (IBM=LOAD(I)) 540, 540, 540
540 WRITE (6, 550)
550 FORMAT (1X, 'EQUIPMENT NUMBER GREATER THAN 500 **********')
560 IF (IBM=LOAD(I)) 580, 580, 570
570 IF (IBM=LOAD(I)) 570, 570, 570
580 IF ( ThếIBM) 590, 610, 590
590 WRITE (6, 600)
600 FORMAT (1X9HEQUIPMENT, I5, 1X34HDEFINED TWICE **********)
610 CONTINUE
620 CONTINUE
630 IF (KS(I) 640, 640, 630
640 WRITE (6, 640)
650 IF (MTTR(I) 650, 650, 650
660 IF (MTTR(I) 660, 660, 660
670 CONTINUE
C
C OREILLY CHANGE
C 650 WRITE (6, 660)
C 660 FORMAT (1X11HSARES TYPE, 6X4HSHIP, 6X4HTENDER, 6X4HBASE, 12X6HPERCTOR)
650 DO 670 T=1, 1
650 DO 670 J=1, NTYPE
670 TUSED(I, J) = 0

C
READ (5, 675) JUNLIN, SX, SPR1, SPR2, SPR3, SPR4, SPR5, SPR6, SPR7, SPR8, SPR9
   1, SPR10, SPR11, SPR12, SPR13, SPR14
675 FORMAT (14, 16X, 1SP4, 0)
   IF (SX .LT. 999) 681, 676, 681
676 CALL SPARES
   IF (KS (1)) 740, 740, 677
677 DO 678 I = 1, WTYPE
678 WRITE (6, 750) I, (ISPARE (J, I), J = 1, 3), SX
   GO TO 740
681 IF (SX) 684, 682, 684
682 SX = 1.0
684 IF (JUNLIN .EQ. BLANK) 690, 720, 690
690 WRITE (6, 700)
700 FORMAT (1X, 'ALL EQUIPMENT TYPES HAVE UNLIMITED SPARES')
   DO 710 I = 1, WTYPE
   DO 710 J = 1, 3
710 ISPARE (J, I) = 90000
   GO TO 760
720 DO 740 I = 1, WTYPE
   READ (5, 10) (ISPARE (J, I), J = 1, 3)
   BILL = FLOAT (ISPARE (1, I)) * SX
   IF (INT (BILL) - BILL) 727, 725, 727
725 ISPARE (1, I) = BILL
   GO TO 728
727 ISPARE (1, I) = INT (BILL) + 1
728 CONTINUE
   IF (KS (1)) 740, 740, 730
730 WRITE (6, 750) I, (ISPARE (J, I), J = 1, 3), SX
   780 CONTINUE
750 FORMAT (5X, 14, 2X, 3110, 13X, F6.2)
C
760 WRITE (6, 770)
770 FORMAT (1X, 'THE MISSION WILL BE RUN WITH 14.7H PHASE 27HTYPE IS IN VARIABLE SEQUENCE.')
C
   DO 777 I = 1, 6
   DO 777 J = 1, 10
   DO 777 K = 1, 60
   ISTB (K, J, I) = 0
775 CONTINUE
776 CONTINUE
777 CONTINUE
   DO 790 K = 1, NPH
   READ (5, 780) XID, LL, NSS (K), ISS (K, NSS (K) + 1), SSTIME (K, NSS (K) + 1, 2)
   ISTS (K) = ISS (K, NSS (K) + 1)
780 FORMAT (14, 114, F8.0)
   MX = NSS (K)
   N = N + 1
IF (KS (1)) 820, 820, 790
790 WRITE (6, 810) IID, LL, NNS (K), ISS (K), SSTIME (K, N, 2)
800 FORMAT (I1A4, 3, I4, F10.2)
810 FORMAT (/1X4, 3, I4, F10.2)
820 TITLE (K, N) = IID
DO 840 IK = 1, NK
READ (5, 780) TITLE (K, IK), KK, MM, ISS (K, IK), SSTIME (K, IK, 2)
IF (KS (1)) 840, 840, 830
830 WRITE (6, 800) TITLE (K, IK), LL, MM, ISS (K, IK), SSTIME (K, IK, 2)
840 CONTINUE
C
DO 850 JA = 1, MAXIB
DO 850 JB = 1, 8
IB (K, JA, JB) = 0
NRO (K, JA) = 0
850 CONTINUE
I=0
860 I=I+1
READ (5, 10) (IVAL (J), J = 1, 10), IRULE
IF (IVAL (1) .EQ. 0) GO TO 990
IF (IRULE .NE. 0) GO TO 930
C
IF (I, LE. MAXIB) GO TO 880
WRITE (6, 870) MAXIB
870 FORMAT (1H1, 10X, 29# OF GROUP CARDS GREATER THAN, I4)
STOP
880 NRO (K, I) = IVAL (1)
DO 890 J = 1, 8
IB (K, I, J) = IVAL (J + 1)
890 CONTINUE
INUM (K, IB (K, I, 1), -500) = I
NLINE (K) = I
900 IF (KS (1)) 860, 860, 910
910 WRITE (6, 920) NRO (K, I), (IB (K, I, J), J = 1, 8)
920 FORMAT (1X, 13, 8I4)
GO TO 860
930 CONTINUE
I = I - 1
IOR = IOR + 1
C
IF (IOR .LE. MAXSTD) GO TO 950
WRITE (6, 940) MAXSTD
940 FORMAT (1H1, 10X, 36# OF OPERATE RULE CARDS GREATER THAN, I4)
STOP
950 CONTINUE
DO 960 J = 1, 10
ISTB (I0B, J, K) = IVAL (J)
960 CONTINUE
   IF (KS(1)) 860, 860, 970
970 WRITE (6, 980) IISTB(IOK, J, K), J=1, 10
980 FORMAT (50X, 10I4)
   GO TO 860
990 CONTINUE
1000 CONTINUE
   RETURN
   END

SUBROUTINE EVENT
   COMMON /ALPHA, DMT2, EMDPH, ICR1, IFF, IFB, INUM, IOPT, JBB, KEQ, KKK, KZZ
1, KK1, KS1, IL, LILLST, NEQ, NPH, NTYPE, NON, REDAD2, REDAD1 (100), BELL, RED2
2, RELAY, RELR, RSTHAS, TF, T1, TCUM, TT3, UP3, IPFEOP, T3, TIME, T3SUM
   COMMON /N/NEQ (500), KEQ (500), ETIM (1000), TINTP (200), TINTT (200)
   COMMON /ISPAKE/XFLAG, BUDGET, COST (201)
C
   R = ABS (ETIM (1))
   KEQ = 1
   DO 20 I = 2, NEQ
      RR = ABS (ETIM (1))
      IF (RR < RH) 20, 20, 10
10 R = RR
      KEQ = I
   20 CONTINUE
   RETURN
   END

SUBROUTINE TTE
   COMMON /ALPHA, DMT2, EMDPH, ICR1, IFF, IFB, INUM, IOPT, JBB, KEQ, KKK, KZZ
1, KK1, KS1, IL, LILLST, NEQ, NPH, NTYPE, NON, REDAD2, REDAD1 (100), BELL, RED2
2, RELAY, RELR, RSTHAS, TF, T1, TCUM, TT3, UP3, IPFEOP, T3, TIME, T3SUM
   COMMON /N/NEQ (500), KEQ (500), ETIM (1000), TINTP (200), TINTT (200)
   COMMON /EXTRA/, KS (20), ISW (31)
   COMMON /NPH, NS (6), IFLAG (6), TITLE (6, 31), SSTIME (6, 31), ISS (6, 31)
   COMMON /TYP, EX (2, 200), ISPAKE (3, 200), ITUSED (3, 200), ITOSLD (3, 200)
   COMMON /DELTA, KKK 2
   COMMON /XX, XKK
   COMMON /VDC/VDC (50, 6), LUI (200), VMTR (200, 6), TAD2
   COMMON /VAR, RELG (100), TIMA (100), XXT (200), IOTTT, ISEED
   COMMON /ISPAKE/XFLAG, BUDGET, COST (201)
C
10 K = KEQ
20  J=IABS(TPOQ(K))
   IF (ETIME(K) .GE. 100000.) 30, 120, 30
30  IF (ETIME(K)) 120, 120, 40
C
40  IF (ABS(XXX) .LT. 9999.) 41, 120, 41
41  DO 60 I=1,2
   IF (ISPARE(I,J) .NE. IUSED(I,J)) 60, 60, 50
50  IUSED(I,J) = IUSED(I,J) + 1
   IUSED(I,J) = IUSED(I,J) + 1
   II = 1
   GO TO 120
60  CONTINUE
   IF (ISPARE(3,J) .NE. IUSED(3,J)) 70, 70, 110
70  IF (ETIME(K) .GE. 100000.) 80, 120, 80
80  ETIME(K) = 5000000.
   IF (KS(12)) 340, 340, 90
90  WRITE (6,100) J
100  FORMAT ('X1: EQUIPMENT TYPE ,I4, 25H HAS CONSUMED ALL SPARES."
   GO TO 340
110  IUSED(3,J) = IUSED(3,J) + 1
   IUSED(3,J) = IUSED(3,J) + 1
   II = 3
C
120  XXX = ABS(XXX)
C
   IF (KKK2) 140, 130, 140
130  TP = 0
   II = 0
140  IF (ETIME(K) .GE. 100000.) 160, 150, 160
150  ETIME(K) = -TP
   GO TO 170
160  IF (ETIME(K)) 170, 170, 180
170  X = 1
   GO TO 190
180  X = -1
190  CALL LRND(IUSED, RN, 1, 16807, 0)
   IF (II-2) 200, 210, 210
200  ADT = 0
   GO TO 220
210  II = II - 1
   ADT = EX(III, J)
220  CONTINUE
   IF (ETIME(K)) 230, 230, 330
230  K1 = IABS(TPOQ(K))
   IF (IUI(K1)) 330, 330, 240
240  IU = IUI(K1)
   ST = 0.0
   SR = 1.0
```
RN3=IN
DO 300 I=JBB,100
  T=IXT (2*I)
  IF (T) 250 320,250
250  IF (ST) 300 260,300
260  T=TIME(I)+ETIME(K)
  IF (T) 270, 310, 300
270  T=0
  GO TO 310
300  LLL=IXT (2*I-1)
  XM=VD(C/14 LL)
  IF (XM) 280, 320, 280
280  R=EXP (-T/XM)
  SB=SB*R
  IF (SR-RM) 320, 320, 290
290  ST=ST+T
  RN3=RN/SB
310  CONTINUE
320  ETIME(K) = ST - (XM*ALOG (RN3) ) + ABS (ETIME(K)) + ADT
  GO TO 340
330  ETIME(K) = 10 (-XXX*ALOG (RM) ) + ABS (ETIME(K)) + ADT
340  IF (IFLAG (LL)-1) 370, 370, 350
350  IF (ETIME(K)+500000.) 360, 370, 360
360  ETIME(K) = 100000.
370  CONTINUE
  RETURN
END

SUBROUTINE STNDBY
COMMON /ALPHA/DNT2, ENDPHA, ICRI, IPP, IPR, INUM, IOPT, JBB, KEQ, KKK, KZZ
  1, X1, X2, Y, Z, LL, LLST, WEO, WPH, MTYPE, WNUM, READ1, READ2, READ3, 100, RLP, RED2
  2, RELT, REPL, STAHAS, TP1, TP2, T1, TCOM, T3, UG3, IFPEOP, T3, TIME, T3SUM
COMMON /N/EQU (50), KEQ (50), ETIME (1000), XMTBF (200), XMTTR (200)
COMMON /XXX/XXX
COMMON /STAN/ISTB (60, 10, 6)
COMMON /ISPARE/IFLAG, BUDGET, COST (201)
DO 170 I=1, 50
  IF (ISTB (I, 1, LL)) 10, 180, 10
C
10  INDEX=1
DO 50 J=2, 10
  KK=ISTB (I, J, LL)
50  C
IF (KK) 30, 60, 20
20 IF (ETIME(KK)) 40, 50, 50
C
30 KK=IABS(KK)
IF (ETIME(KK)) 40, 40, 50
40 INDEX=0
GO TO 60
50 CONTINUE
C
60 K=IABS(ISTB(I, 1, LL))
C
ISO=ISTB(I, 1, LL)
C
70 IF (ETIME(K)) 170, 170, 80
80 IF (ETIME(K)) 1000, 120.90, 120
90 IF (INDEX) 170, 110, 100
100 IF (ISO) 170, 170, 150
110 IF (ISO) 150, 170, 170
120 IF (INDEX) 170, 140, 130
130 IF (ISO) 160, 170, 170
140 IF (ISO) 170, 170, 160
C
150 IABC=IABS(LPEQUI(K))
160 XI=xntbp(IABC)
170 KEQ=K
180 CALL TTE
190 GO TO 170
C
160 ETIME(K)=100000.
170 CONTINUE
180 RETURN
END

SUBROUTINE STATUS
COMMON /ALPHA, DMT2, ENDPHA, ICRI, IFF, IFR, INUM, IOPT, JBB, KEQ, KKK, KZ2
1, KK1, KST, LL, LLST, KEQ, NPH, NTPE, NUR, REDAD2, REDAD1(I, 100), RELF, RED2
2, RELY, REPO, STPHAS, TE, T1, ICUM, T3, UP3, IPPEOP, T3, TIME, T3SUM
COMMON /BETA, NRO(6, 300), IB(6, 300, 8), NLINE(6)
COMMON /EXTRA/ KS(20), JSW(31)
COMMON /IN/ LPEQUI(500), KEQU(500), ETIME(1000), XNTBP(200), XNTTR(200)
COMMON /NPH/ RNS(6), IFLAG(6), TITLE(6, 31), SSTIME(6, 31, 2), ISS(6, 31)
COMMON /XSPACE/XFLAG, BUDGET, COST(201)
C
KID=0
SUBROUTINE APPLE
DIMENSION IPRMT(50), ICHLD(50), HKBA(100)
COMMON /ALPHA/DAM2, EDMHA, ICRI, IFF, IFR, INUM, IOPF, JB8, KEQ, KKK, KZZ
+KK1, KS1, LL, LLASL, LEQ, MM, NTYPE, NTH, REDAD2, REDA1(100), RELF, RED2
+RELY, REPOL, STPHA5, TF, T1, XCMN, T2, UP3, IPPEOP, T3, TIME, T3SUM
+COMMON /BETA/IMO(6, 300), IB(8, 300, 8), LINE(6)
COMMON /MO/LEQ(500), KEQO(500), ETIME(1000), XMTEB(200), XMTEB(200)
COMMON /TIGAP/UP4, INUM, BAPRI, AVA, XCAP, RNUMD(19), TICCOO(500)
+COUNTB(500), XTCUM
COMMON/RUNAP/ITEMP2, DELT, ISSA(31), ISSC
COMMON/WPH/KSS(6), IFLAG(6), TITLE(6,31), SSTIME(6,31,2), ISS(6,31)
COMMON/PACKAP/I8NHUM(6,500), ISS(6), F(200,4)
COMMON/XSPARE/XFLAG, BUDGET, COST(201)

C IF (BAPRIN) 790, 90, 90
90 JCOUNT=0

100 IPTR=0
L=LL
IF (ITEMP2) 240, 105, 107
105 K=IBNUM(L, ISS(L) - 500)
GOTO 108
106 KSS=ISSA(ISSC)
K=IBNUM(L, KSS(L, KSS) - 500)
108 KID1=IB(L, K, 1)
110 NN=2

C DO 210 N=NN, 8
IGRP=IB(L, K, N)
IF (IGRP) 240, 212, 140
140 IF (ETIME(IGRP)) 150, 150, 210
150 IF (IGRP-500) 170, 170, 160

C IF (JCOUNT) 240, 200, 180
170 IF (JCOUNT) 240, 200, 180
180 DO 190 I=1, JCOUNT
IF (MKBA(I) - IGRP) 190, 210, 190
190 CONTINUE
C JCOUNT=JCOUNT+1
MKBA(JCOUNT)=IGRP
210 CONTINUE
212 IF (K-1) 220, 220, 214
214 KID2=IB(L, K-1, 1)
IF (KID1<KID2) 220, 216, 220
216 K=K-1
GOTO 108
220 IF (IPTR) 240, 260, 230

C IF (IPTR) 240, 260, 230
230 K=IPRNT(IPTR)
KID1=IB(L, K, 1)
NN=ICHLO(IPTR)
IPTR=IPTR-1
GOTO 120

C 160 IF (N-8) 165, 167, 240
C 165 IPTR=IPTR+1
IPRNT(IPTR) =K
ICHID(IPTB) = NW+1
167 NW = EBNOH(L, LGBR=500)
GOTO 108
240 WRITE (6, 250)
250 FORMAT (12H APPLE ERROR)
GO TO 300
C
260 IF (ITEMP2) 240, 265, 262
262 ISSC=ISSC-1
IF (ISSC) 240, 265, 100
265 FCOUNT=FLOAT(JCOUNT)
IF (ITEMP2) 270, 270, 280
C
270 DO 275 I=1, JCOUNT
275 TYCOON(MKBA(I)) = TYCOON(MKBA(I)) + DELT/FCOUNT
GOTO 300
C
280 DO 290 I=1, JCOUNT
290 COUNTB(MKBA(I)) = COUNTB(MKBA(I)) + 1/FCOUNT
300 CONTINUE
RETURN
C
790 CONTINUE
WRITE (6, 800) (RUNID(I), I=1, 19)
800 FORMAT (19I2, 1X, 19A4/)
WRITE (6, 810)
810 FORMAT (12X 19HCritical equipments //32X, 18Hunavailability and//
1X 25HEPercent of unavailability//)
WRITE (6, 820)
820 FORMAT (24X HNAME, 17X HNUM, HRS, 11X HUNAVA, 2X HPERCENT, 6X HQU TYPE-1, 5X HSEQI NUM/)
C
830 IF (AVA-1.) 830, 880, 830
830 TR=TYCOON(1)
INDEX=1
DO 850 I=2, NEQ
TR=TYCOON(I)
IF (TR-TRR) 840, 850, 850
840 TR=TRR
INDEX=1
850 CONTINUE
TYCO=TYCOON(INDEX)/TT3
TYCO2=TYCOON(INDEX)/(TT3-UP4) * 100.
IF (TYCOON(INDEX)) 860, 880, 860
860 IXX=ABS(IEOQ(INDEX))
WRITE (6, 870) (F(IXX, J), J=1, 4), TYCOON(INDEX), TYCO, TYCO2, IXX
1, INDEX
870 FORMAT (20X 4A4, F20.4, 4XP8.4, F8.2, 6X 1, 10 14)
TYCOON(INDEX) = 0.0
GO TO 830
880 WRITE (6, 800) (RUNID(I), I=1, 19)
WRITE (6, 910)
910 FORMAT (32X, 19HCRITICAL EQUIPMENTS/32X, 17HUNRELIABILITY AND/
127HPERCENT OF MISSION FAILURES/) WRITE (6, 920)
920 FORMAT (12X, 1HDESCRIPTION, 8X, 3HNO. 6XHUNREL, 3XHPERCENT, 2XHEQUIP
IP, EQUIP/28XHFAILURES, 2X10HTYPE NO.) IF (XPCAP =-1.) 930, 1090, 930
C 930 INEW = 0
DO 950 I = 1, NEQ IF (COUNTB(I)) 950, 950, 940
940 INEW = INEW +1
MKBA(INEW) = I
950 CONTINUE
C 955 IF (INEW =-1) 1010, 975, 952
952 INDEX = MKBA(1)
NN = 1
TR = COUNTB(INDEX)
DO 970 I = 2, INEW IF (TR = COUNTB(MKBA(I))) 960, 970, 970
960 INDEX = MKBA(I)
NN = I
TR = COUNTB(INDEX)
970 CONTINUE
977 UNREL = TR/XNUM
PERC = TR/TOTAL*100.
IND = IABS (IEQU(INDEX)) WRITE (6, 990) (P(I, IND), J = 1, 4), TR, UNREL, PERC, IND, INDEX
990 FORMAT (9X4A4, 3XP6.1, 5XP6.4, 3XP6.2, 4X14, 3X14)
MKBA(1) = MKBA(INEW)
INEWA = INEW -1
GOTO 955
975 INDEX = MKBA(1)
TR = COUNTB(INDEX)
GOTO 977
1010 JNUM = IFIX (XNUM)
WRITE (6, 1020) JNUM
1020 FORMAT (6H9F19HTOTAL NO. MISSIONS=, F14)
ITOTAL = TOTAL
WRITE (6, 1030) ITOTAL
1030 FORMAT (9X2HTOTAL NO. MISSION FAILURES=, Z4)
1090 RETURN
END
SUBROUTINE SPARES

COMMON /ALPHA/DM2, EMNPHA, ICRI, IFP, IFR, INUM, IOPT, JBB, KEQ, KKK, KZZ
1. KKL, KSL, LLL, LLLAST, MEO, MPP, NTYPE, NUM, REDAD2, REDAD1(100), RELP, RED2
2. RELPY, REPO, SPHAS, SP, T1, TCOM, T3, T63, IPFEOP, T3, TIME, TSSUM
COMMON /W/EQU (500), KEQU (500), ETIME (1000), XMTBE (200), XMTTR (200)
COMMON /TYPE EX (2, 200), ISPAR (3, 200), IUSED (3, 200), IIUSED (3, 200)
COMMON /CSPARE, /S, /PR1, /PR2, /PR3, /PR4, /PR5, /PR6, /PR7, /PRB, /PR9
1. /PR10, /PR11, /PR12, /PR13, /PR14, /ITMP (200)

OREILLY ADD
COMMON /ISPAR /XFLAG, BUDGET, COST (201)
COMMON /KSPARE /JTIME, TOTSPR
IF (XFLAG = 1) 5, 2, 3
2 CALL MSPARE
  WRITE (6, 22)
  GO TO 101
3 CALL GSPARE
  WRITE (6, 22)
  GO TO 101
5 CUT=SPR1
  XAVAIL = .9
  XBUDL = .85 * BUDGET
  XBUDH = 1.05 * BUDGET
  WRITE (6, 301) XBUDH
301 FORH (1 / IX, 5HBUDH, F8.2)
  HIGH = 1.
  LOW = 0.0
  WRITE (6, 6)
  FORMAT (/ 1X, 33HSPARES BEING COMPUTED USING FLSIP)
  WRITE (6, 303) XAVAIL
C OREILLY STOP
  DO 10 I = 1, NTYPE
    ITMPOP (I) = 0
  10 CONTINUE
  DO 20 I = 1, NEO
    ITMPOP (IEQU (I)) = ITMPOP (IEQU (I)) + 1
    CONTINUE
20 CONTINUE
  DO 25 I = 1, NTYPE
    EX90DD = (E8766 / XMTBF (I)) / 4. * ITMPOP (I)
    IP (EX90DD - 1.) 60, 30, 30
C
30 PRBSUM = EXP (-EX90DD)
  DUR = PRBSUM
  KFACT = 1
40  K=0
41  K=K+1
42  KFACT=KFACT*K
43  PRBSUM=1-RBSUM+DUM*(EX90DD*K)/KFACT
44  IF(PRBSUM-XAVAIL) 40,50,50
50  ISPARE(1,I)=K
51  GO TO 90
60  IF(4.*EX90DD-CUT) 80,80,70
70  ISPARE(1,I)=1
71  GO TO 90
80  ISPARE(1,I)=0
90  CONTINUE
91  ISUM=0.0
92  DO 95  I=1,NTYPE
93  ISUM1=ISPARE(1,I)*COST(I)
94  ISUM=ISUM+ISUM1
95  CONTINUE
96  XSUM=ISUM/COST1
302  FORMAT(/1X,5HXSUM,F8.2)
303  IF (XSUM-X6BUD) 206,200,205
97  WRITE (6,98) XAVAIL
98  FORMAT(/17,4=H,PSLIP ALLOWS CONSTRAINED BY BUDGET, XAVAIL=,F8.6)
99  DO 100  I=1,NTYPE
100  J=2,3
101  ISPARE(J,I)=0
102  CONTINUE
103  END
104  WRITE (6,22)
22  FORMAT(/1X11HSPARES,TYP,6X4HSHOP,4X6HTENDER,6X4HBASE,12X6HFACTOR)
201  RETURN
200  IF(XAVAIL-.9) 91,97,99,99
204  IF(XAVAIL-.1) 208,206,206
206  XAVAIL=XAVAIL-.05
207  WRITE (6,303) XAVAIL
208  GO TO 25
209  DO 215  I=1,NTYPE
210  J=1
211  ISPARE(J,I)=0
212  K=K+1
213  GO TO 97
C  GO TO 25
C  END
C  STOP
SUBROUTINE MSPARE

MARGINAL ANALYSIS MODEL WITH COST CONSTRAINT READ IN SEPARATELY

COMMON /ALPHA/DMT2, EMDPHA, TCRI, IPP, TPB, INUM, JOPT, JPR, KEO, KKK, KZ, K1, KS, LLAST, NEO, NBR, NTYP, WNR, REDAD2, REDAD1(100), RELP, RED2, RELT, REPO, T1, T11, KSUM, T3, UBS, IPPEOP, T3, TIME, T3SUM

COMMON /N/EQU(500), KEOU(500), ETIME(1000), INTBP(200), INTTR(200)

COMMON /TPRZ(2, 200), ISPARSE(3, 200), IUUSED(3, 200), IUUSED(3, 200)

COMMON /CSPARSE/ SPR1, SPR2, SPR3, SPR4, SPR5, SPR6, SPR7, SPR8, SPR9

1 SPR10, SPR11, SPR12, SPR13, SPR14, ITMPOP (200)

COMMON /KSPACE/XFLAG, BUDGET, COST (201)

COMMON /KSPACE/TIME, TOTSPR

DIMENSION PBRSUM (201)

DIMENSION PBSUPA (201)

DIMENSION PBRSU (201)

DIMENSION DON (201)

DIMENSION K (201)

DIMENSION KFACT (201)

DIMENSION BUDGET (201)

DIMENSION PBRSUE (201)

NTYPE1 = NTYPE + 1

COST (NTYPE1) = 9. E10

PBRSU(NTYPE1) = 0

BUDGET = BUDGET

XFLAG = 0

WRITE (6, 1) 48H SPARES WILL BE DETERMINED WITH MARGINAL ANALYSIS

WRITE (6, 2) BUDGET IS .F8.0

1 FORMAT (1X, 48H SPARES WILL BE DETERMINED WITH MARGINAL ANALYSIS)

2 FORMAT (1X, 10H BUDGET IS .F8.0)

SET INITIAL STOCKS TO ZERO (SHIP/ TENDER/ DEPOT)

DO 5 I = 1, NTYPE

DO 5 J = 1, 3

ISPARSE(J, I) = 0

4 FORMAT (1X, 24H SPARE MATRIX SET TO ZERO)

CONTINUE

DETERMINE EXPECTED FAILURES IN 90 DAYS AND DETERMINE PROBABILITY

OF NO STOCKOUTS IN 90 DAYS IF ZERO SPARES ARE CARRIED.

DO 6 I = 1, NTYPE

ITMPOP(I) = 0

CONTINUE

DO 7 I = 1, NEO

ITMPOP (IEQU (I)) = ITMPOP (IEQU (I)) + 1
7 CONTINUE
   DO 10 I=1,NTYPE
   EX90DD(I) = ((67.66./(INTEP(I)) \* ITMPOP(I)
   PRBSUM(I) = ZIP(-EX90DD(I))
   DUM(I) = PRBSUM(I)
8   FORMAT(1X,17HITEM POP DETERMINED)
9   FORMAT(1X,16HITEM POP FOR ITEM I4,3X,F8.3)
10  CONTINUE
12  FORMAT(1X,16HITEM POP FOR ITEM I4,4H IS ,I4)
13  FORMAT(1X,16HNTYPE AND NEQ ARE ,I4,I4)
14  FORMAT(1X,11HIEQU(I) IS ,I4)

CCC  K = NUMBER OF SPARES
   DO 20 I=1,NTYPE
                   K(I)=1
   KFACT(I)=1
   WRITE (L,15) I,COST(I)
15  FORMAT(1X,17HCOST OF ITEM I4,4H IS ,F8.2)
20  CONTINUE

CCC  DETERMINE PROBABILITY OF NO STOCKOUTS WITH ONE MORE SPARE THAN PRBSUM.
   DO 25 I=1,NTYPE
       PRBSUM(I)=PRBSUM(I)+DUM(I)\*(EX90DD(I)\*K(I))/KFACT(I)
25  CONTINUE

CCC  CALCULATE MARGINS BETWEEN PRBSUM AND PRBSUM
   DO 30 I=1,NTYPE
       PRBSUM(I)=PRBSUM(I)-PRBSUM(I)
       PRBSUM(I)=PRBSUM(I)/COST(I)
30  CONTINUE

CCC  SELECT LARGEST MARGIN
   I=1
   DO 50 J=2,NTYPE1
   IF (BUDLEF-COST(I) ) 40,35,35
   IFLAG=1
   IF (PRBSUM(J)-PRBSUM(I) ) 50,50,45
35  I=J
   GO TO 50
   IF (BUDLEF-COST(J) ) 50,40,40
45  GO TO 50
C 50 CONTINUE

IF ONE MORE OF ANY SPARE IS ALLOWED, INCREMENT SPARES ALLOWANCE, OR ELSE QUIT.

55 IF(SPLAG-1) 100, 60, 100

IF ONE MORE SPARE IS ALLOWED, INCREMENT SPARES ALLOWANCE AND ADJUST REMAINING BUDGET LEFT.

60 ISPARE(1,I) = ISPARE(1,I) + 1
BUDLEF = BUDLEF - COST(I)
K(I) = K(I) + 1
PBSSUM(I) = PBSSUM(I) + PBSSUB(I)
PRBSUR(I) = PRBSUR(I) + (EXPADD(I)/K(I))
PRBSSD(I) = PRBSSD(I) + PBSSUB(I) / COST(I)
PRBSUA(I) = PRBSUA(I) + PBSSUE(I)
SPLAG = 0
GO TO 31

C 100 WRITE (6, 101)
101 FORMAT (1I, 29HALL SPARES HAVE BEEN COMPUTED)
RETURN
END

SUBROUTINE GSPARSE

AVAILABILITY ROUTINE DEVELOPED BY MAN WON JEE

COMMON /ALPHA,DNT2,ENDPHA,ICRL,IFP,IFP,INUM,LOPT,JBB,KEQ,KKK,KZZ
1,1G1,KS,LLLLLST,HEQ,MPH,MYTYPE,NUM,REDAD,REDAD1(100),RELP,RED2
2,RELPY,REPOL,SRPAS,SP1,SP2,SP3,SP4,SP5,SP6,SP7,SP8,SP9
1,SPR1,SPR12,SPR13,SPR14,SPR15,SPR2
COMMON /ISPARE/XFLAG,BUDGET,COST(200)
COMMON /ISPARE/XTIME,TOTSPR,COMBA(10000),COMBA(10000),SER(100)
INTEGER NOSP,COMB,COMBA,SER
DIMENSION LAMBDA(200),JSPARE(50,200),ETA(200),THETA(200)
DIMENSION DELTA(200),PRE(50),IPRES(50)
COMMON /GEOG/NOSP,AVAIL(200,50),CCOST(200,50),SPRS(200,50)
REAL JSPARE, LAMBDAA, ETA, DELTA, IEXP, EMLT, TOD, PROD, XRES!
REAL XRESR, EM, ILAST, FRR, FACTOR, SUK, ETF, TODS, I500, D, ILAST1, PKL
REAL PROD1, SUK1, SUK11, AVAIL, BVAR, FCTOR2, JTIME1, JTIME2, GTIME
REAL COST
INTEGER AVAR, R, FACTOR, LVAR, K, TOTSPR, JVAR, SPRS

C
WRITE (6, 1)
1 FORMAT (/1X, 39HSPARES BEING COMPUTED USING JEE FORMULA)
WRITE (6, 2) JTIME
2 FORMAT (/1X, 9HJTIME IS ,I8)
GTIME=FLOAT (JTIME)
WRITE (6, 3) TOTSPR
3 FORMAT (/1X, 10HTOTSPR IS ,I4)
C
SET INITIAL STOCKS TO ZERO (SHIP/TENDER/DEPT)
DO 5 I=1, NTYPE
DO 5 J=1, 3
ISPARE(J, I) = 0
5 CONTINUE
C
SET GPARE AVAILABILITY MATRIX TO ZERO
AVAR=TOTSPR+1
DO 10 I=1, NTYPE
DO 10 J=1, TOTSPR
AVAIL(I, J) = 0
10 CONTINUE
C
CALCULATE LAMBDAS, ETAS, THETAS, AND DELTAS
DO 13 I=1, NTYPE
LAMBDAA(I) = 1/XMTBP(I)
13 CONTINUE
C
DO 14 I=1, NTYPE
ETA(I) = 1/XMTTR(I)
14 CONTINUE
C
DO 15 I=1, NTYPE
THETA(I) = LAMBDAA(I) * ETA(I)
15 CONTINUE
C
DO 16 I=1, NTYPE
DELTA(I) = ETA(I) - LAMBDAA(I)
16 CONTINUE
CALCULATE GSPARE AVAILABILITIES WITH ZERO SPARES

DO 16 I = 1, NTYPE
   AVAIL(I, I) = EXP(-LAMBDA(I) * GTIME)
SPRS(I, 1) = 0
CCOST(I, 1) = 0.0
16 CONTINUE

CALCULATE AVAILABILITIES FOR EACH I (THRU NTYPE) WITH K SPARES (THRU TOTSPR)

DO 300 I = 1, NTYPE
  FIND XPRES1: FIRST HALF OF AVAIL EQUATION
  FOR K = 1, WE FIND SUM TO BE:
    EM = EXP(-LAMBDA(I) * GTIME)
    THD = THETA(I) / DELTA(I)
    PROD = THD
    XPRES1(1) = (GTIME - 1. / DELTA(I)) * PROD * EM
CC
  NOW INITIALIZE OTHER VARIABLES
    IX = GTIME
    IXLAST = 1
    PKR = 1

IF (TOTSPR - 1) 110, 110, 30
30 DO 100 K = 2, TOTSPR
CC
CALCULATE PKR FOR B = 1 USING RECURSIVE EXP NO. 1

   PKR = IX * IXLAST / (K - 1) ** 2
   IXLAST = PKR
   JV = K - 1
   JTIME1 = GTIME ** JV
   JTIME2 = JTIME1 / DELTA(I)
   FACTOR = (-1.) * JTIME2
   SUMK = FACTOR * PKR
552 FORMAT (/IX, 7HSUMK = , E10.4)
CC
  NOW SUM OVER B = 2 TO K; CALCULATE USING RECURSIVE EXP NO. 2

DO 50 B = 2, K
   PKR = (K * (B - 1)) * (K - (B - 1)) * PKR / B
   IX = IX * GTIME / K
   XPRES1(K) = (IX + SUMK) * EM / PROD
50 CONTINUE

100 CONTINUE
C FIND XRES2: SECOND HALF OF AVAL EXPRESSION

C FOR K=1, WE FIND SUM TO BE:
   IF ETA(I) GTIME 25.0 110, 110, 109
109 EMET=0
   GO TO 117
110 EMET=EXP(-ETA(I)*GTIME)
111 FORMAT (1X,26H1,EMET,ETA, AND TIME ARE: ,I4,E12.5,F8.5,F8.1)
112 TODSO=THETA(I)/DELTA(I)**2
113 XRES2(I)=TODSO*EMET
   IF (TOTSPR-1) 204, 204, 120
C FOR K=2, WE FIND SUM TO BE:
120 TSOOD3=TODSO*(THETA(I)/DELTA(I))
   IF (TOTALS-2) 204, 204, 140
C NOW INITIALIZE VARIABLES

C 140 XLAST1=3/DELTA(I)
    PCTOR2=GTIME
    FKL=3/DELTA(I)
    PROD1=THETA(I)**2/DELTA(I)**3
    PCTOR1=-1.

C DO 205 K=3, TOTSPR

C C CALCULATE FKL FOR L=1 USING RECURSIVE EXP NO. 3
C C FKL=XLAST1*GTIME*(1./K-2)*(1./K)*(K+1)
C C XLAST1=FKL
C C SUNK1=FKL

C NOW SUM OVER L=2 TO K-1 USING RECURSIVE EXP NO. 4
C C LVAR=K-1
C DO 150 L=2, LVAR
C C FKL=FKL*(K-L)*(K+L)*(1./L)
C C FKL=FKL/(GTIME*DELTA(I))
C C SUNK1=SUNK1+FKL
150 CONTINUE
C C PCTOR2=PECTF2*GTME/(K-1)
C C SUNK11=PECTF2*SUNK1

C 204 PROD1=PROD1*(THETA(I)/DELTA(I))
C C PCTOR1=PECTF1*[-1.]
C C XRES2(K)=PECTF1*PROD1*EMET*SUNK11

205 CONTINUE
BECAUSE SPARES AVAILABILITY IS INDEXED AS 1 DO:
DO 250 K=1, TOTSPR
   AVAIL (I, K+1) = XPRES1(K) * XPRES2(K) + AVAIL (I, K)
   CCOST (I, K+1) = COST (I) * K
   SPRS(I, K+1) = K
250 CONTINUE
300 CONTINUE
DO 450 I=1, NTYPE
   WRITE (6, 350) I
350 FORMAT (/IX, 29, 'HAVALIABILITY MATRIX FOR SPARE, I3, 4H IS:
   DO 440 J=1, AVAR
      WRITE (6, 370) I, SPRS (I, J), CCOST (I, J), AVAIL (I, J)
440 CONTINUE
450 CONTINUE
CALL GEEALG
RETURN
END

SUBROUTINE GEEALG

ALGORITHM DEVELOPED BY GEE FOR DETERMINING OPTIMAL SPARES COMBINATIONS

COMMON /ALPHA/DNT2, EMDPHA, ICR1, IPP, IPR, INUM, IOPT, JB, KEQ, KKK, Z
1, K1, KS1, LL, ILLAST, NEQ, NPH, NTYPE, NON, RADI2, RADA1(100), REL, RED2
2, RELFY, REPOL, STPHAS, TP, T1, ICUM, TT, U43, IFPEOP, T3, TIME, T3SUM
COMMON /NP, DEQU (500), KEQ (500), ETIME (1000), XMTRP (200), XMTR (200)
COMMON /TYP/IX (2, 200), ISPARE (3, 200), IUSED (3, 200), IIUSED (3, 200)
COMMON /CSPARSE/ SPR1, SPR2, SPR3, SPR4, SPR5, SPR6, SPR7, SPR8, SPR9
1, SPR10, SPR11, SPR12, SPR13, SPR14, ITMP (200)
COMMON /KSPARE/ JTIME, TOTSPR, COMB (9999), COMBA (9999), SER (100)
COMMON /NPSPR, COMB, COMBA, SER
COMMON /ISPARE/XFLAG, BUDGET, COST (210)
COMMON /GEALS/NOSP, AVAIL (200, 50), CCOST (200, 50), SPR (200, 50)
DIMENSION LAMBDA (200), JSPARE (50, 200), ETA (200), THETA (200)
DIMENSION DELTA (200), XPRES1 (50), XPRES2 (50)
INTEGER OPT, IOPT, MATV, CSPRS (1111, 20), PI, FIXA, IVAR, IVARB
INTEGER IVAR1, IVAR2, NCAND, PK, PJ, PL, PL, LI, LL, LIVAR (999)
REAL AVAIL (9999), CCOST (9999), PAVAL, PCOST, WCOST, NAVAL
REAL JSKRE, LAMBDA, THETA, ETA, DELTA, JEXP, EMIL, TOD, PROD, XPRES
REAL XPRES, KB, XLAST, KB, FACTOR, SUMK, EMIL, TOSO, TSOOD, ILAST1, PK
REAL PROD1, SUM1, SUM2, AVAIL, BVAR, FCTOR2, JTONE1, JTONE2, GTIME
REAL CCOST
INTEGER AVAR, B, FACTOR1, LVAR, K, TOTSPR, TOTSP, JVAR, SPRS
INTEGER HOLD7, HOLD8, COMBIN, OPT1, OPT2

C
C WRITE(6,1100)
C*****************************************************************************
C** SET INITIAL VARIABLES.
C*****************************************************************************
C MATV=1
TOTS = TOTSPR+1
HOLD7 = 0
HOLD8 = 0
COMBIN = 101
C*****************************************************************************
C CHANGE AVAIL, CCOST AND SPRS FIGURES TO AVAILO, CCOSTO, CSPRS.
C*****************************************************************************
C*****************************************************************************
DO 20 I=1, NOSPRS
J=I*10
DO 15 K=1, TOTS
AVAIL0(J) = AVAIL(I, K)
CCOST0(J) = CCOST(I, K)
SPRS(J, K) =SPRS(I, K)
J=J+1
15 CONTINUE
20 CONTINUE
C*****************************************************************************
C CHECK FIRST INPUT COMBINATION
C*****************************************************************************
C J=COMB(MATV)
L=COMB(A(MATV))
IF(J-1) 30, 32, 32
30 WRITE(6,1101)
GO TO 1000
C*****************************************************************************
C CHECK SUBSEQUENT INPUT COMBINATIONS
C*****************************************************************************
C
```plaintext
31 J=COMB(MATV)
   L=COMB(MATV)
61
62 IF J=0 THEN STOP
63
64 IF(J-1.) 1200,33,33
65     IF(J-70.) 36,94,55
66     WRITE (6, 1103)
67     GO TO 1000
68     J=J+10
69     IF(L-70.) 37,34,45
70     IF(HOLD7-1.) 43,38,38
71     IF(HOLD8-1.) 40,39,39
72     WRITE (6, 1103)
73     GO TO 1000
74
75 801 COMBINATION FROM 2 ORIGINAL INPUTS
76
77 40 OPT1=801
78     HOLD8=COMBIN
79     IVARA=J+TOTSPR
80     IVARB=L+TOTS
81     GO TO 125
82
83 FIRST COMBINATION:RESULTING MATRIX = 701
84
85 43 OPT1=701
86     HOLD7=COMBIN
87     IVARA=J+TOTSPR
88     IVARB=L+TOTS
89     GO TO 125
90
91 IF(HOLD7-L) 50,46,50
92
93 OPT1=701
94     HOLD7=COMBIN
95     L=701
96     IVARA=J+TOTSPR
97     IVARB=IVAR(701)
98     GO TO 125
99
100 IF(HOLD8-L) 51,52,51
101 WRITE (6, 1103)
102 GO TO 1000
```
**J IS TO BE COMBINED WITH EXISTING 801 COMBINATION.**
RESULTING MATRIX = 801.

```
52 OPT=801
   HOLD8=COMBIN
   L=801
   IVARR=J*TOTSPR
   IVARR=IVAR(801)
   GO TO 125
```

```
55 IF(L=70.) 58,34,56
```

**J AND L ARE EXISTING MATRICES, RESULTING MATRIX = 701.**

```
53 OPT=701
   HOLD7=COMBIN
   HOLD8=0
   J=701
   L=801
   IVARR=IVAR(701)
   IVARR=IVAR(801)
   GO TO 125
```

```
58 L=L*10
```

```
60 IF(HOLD7-J) 60,59,60
59 OPT=701
   HOLD7=COMBIN
   J=701
   IVARR=IVAR(701)
   IVARR=L*TOTSPR
   GO TO 125
```

```
60 IF(HOLD8-J) 51,62,51
```

**L IS BEING ADDED TO EXISTING 801 COMBINATION.**
RESULTING MATRIX = 801.

```
62 OPT=801
   HOLD8=COMBIN
   J=801
   IVARR=IVAR(801)
   IVARR=L*TOTSPR
```

**
START COMPUTING NEW MATRIX COMBINATIONS RESULTING

MATRIX = 901 INITIALLY AND THEN CONVERTED TO 701 OR 801.

FIRST COMBINATION IS ALWAYS UPPER LEFT CORNER.

TRANSFER J SPARES TO OPT SPARES.

TRANSFER L SPARES TO OPT SPARES.

CHECK TO SEE IF MAX COMBINATIONS HAVE BEEN COMPUTED.
CHECK TO SEE IF MAX J REACHED.

IF (J-IVAR) 161, 190, 190

NEXT POSSIBLE BEST COMBINATION IN QUAD III IS J+1, L.

161 IF (SEL (MATV) = 1.) 163, 162, 162
162 PAVAIL = AVAILO (J+1) * AVAILO (L)
GO TO 164
163 PAVAIL = 1. - ((1. - AVAILO (J+1)) * (1. - AVAILO (L)))
164 PCOST = CCOSTO (J+1) + CCOSTO (L)
PJ = J+1
PL = L

CHECK TO SEE IF MIN L REACHED.

IF (L-IVAR) 200, 200, 170

NEXT POSSIBLE CANDIDATE IS J+1, L-1.

170 NCOST = CCOSTO (J+1) + CCOSTO (L-1)
171 IF (SEL (MATV) = 1.) 172, 171, 171
171 MAVAIL = AVAILO (J+1) * AVAILO (L-1)
GO TO 173
172 MAVAIL = 1. - ((1. - AVAILO (J+1)) * (1. - AVAILO (L-1)))

MAVAIL MUST EXCEED PREVIOUS OPT AVAL.

173 IF (AVAILO (OPT-1) - MAVAIL) 174, 185, 185

NCOST MUST BE LESS THAN PREVIOUS PCOST.

174 IF (NCOST - PCOST) 175, 500, 180

IF MAVAIL GT OPT AVAL AND NCOST LT PCOST THEN J+1, L-1
IS NEW BEST CANDIDATE.

175 PAVAL = NNAVIL
PCOST = NCOST
PJ=J+1
PL=L-1

CHECK TO SEE IF MIN L REACHED.

180 L=L-1
IF(L-IVAR2) 181,181,170

IF MIN L REACHED, GO BACK TO PREVIOUS OPT AND SEARCH QUAD II.

181 L=LL
J=LJ
GO TO 200

SINCE NAVAIL IS TOO SMALL, ADD 1 TO J IF NOT AT MAX J.

185 IF((J+1)-IVARA) 186,187,187
186 J=J+1
GO TO 170

IF MAX J REACHED, GO BACK TO PREVIOUS OPT AND SEARCH QUAD II.

187 L=LL
J=LJ
GO TO 200

IF NO CANDIDATE IN QUAD III, GO TO QUAD II.

190 NCAND=1
GO TO 200

COMPUTE MAX OPTIMAL IN UPPER RIGHT HAND QUADRANT
**CHECK TO SEE IF MAX L REACHED.**

**NEXT CANDIDATE IS J, L+1.**

**NEXT CANDIDATE IS J, L+1.**

**NCOST MUST BE LT PCOST.**

**NAVAIL MUST BE LT OPT AVAL.**
** NEXT CANDIDATE IS J-1,L+1. **

```
220 J=J-1
225 L=L+1
```

** MAX COMBINATION FOR THIS OPT HAS BEEN REACHED. **

```
250 AVAIL (OPT)=PAVAIL
COST (OPT)=PCOST
DO 255 I=1,NOSPERS
252 CSPRS (OPT,PJ,I)-1.)=253,252,252
253 CSPRS (OPT,PL,I)=253,254,254
254 CSPRS (OPT,PJ,I)=CSPRS (PL,I)
255 CONTINUE
IVAR (PIX)=IVAR (PIX) +1
J=PJ
L=PL
LJ=PJ
LL=PL
```

** CHECK TO SEE IF BUDGET CONSTRAINT EXCEEDED **

```
256 IF (COST (OPT)-BUDGET) LT 257,290,290
```

** CHECK FOR MAX J AND MAX L **

```
257 IF (J-IVARA) LT 154,258,258
258 IF (L-IVARB) LT 154,259,259
259 GO TO 290
```

** BUDGET CONSTRAINT HAS BEEN EXCEEDED. **

```
268 WRITE (6,289)
269 FORMAT (I8,B8) BUDGET FOR OPTIMAL COMBINATION CANNOT BE REACHED
```

** COMPUTATIONS FOR THIS MATRIX ARE COMPLETE. **
290 LOPT=OPT
IVAR (FIX) = IVAR (FIX) - 1.
IF (OPT1-701.) 311 310, 311

291 ITS=IVAR (FIX)
OPT2=OPT1
DO 293 I=901, ITS
AVAIL (OPT2) = AVAIL (I)
CCOSTO (OPT2) = CCOSTO (I)
    DO 292 K=1, NOSPRS
    CSPRS (OPT2, K) = CSPRS (I, K)
    CSPRS (I, K) = 0
    CONTINUE
292 OPT2=OPT2+1
293 CONTINUE

294 IVAR (OPT1) = RESULTING MATRIX IVAR.
IVAR (OPT1) = IVAR (FIX) - FIX+OPT1
MATV=MATV+1
COMBIN=COMBIN+1
GO TO 31

299 LOPT=OPT-1
IVAR (FIX) = IVAR (FIX) - 1.
IF (OPT1-701.) 311, 310, 311

310 HOLD7=COMBIN
LOPT=LOPT-FIX+701
GO TO 291
311 IF (OPT1-801.) 34, 312, 34
312 HOLD8=COMBIN
LOPT=LOPT+801
GO TO 291
500 IF (NAVAIL-PAVAIL) 180, 180, 175
510 IF (MCOST-PCOST) 215, 515, 220
515 IF (NAVAIL-PAVAIL) 220, 220, 215
1000 RETURN
1200 DO 1250 I=1,NOSPRS
ISPARE(I,1)=CSPRS(LOPT,1)
1250 CONTINUE
GO TO 1000
17 FORMAT(1X,7HSPARES FOR ITEM, 14, 9HAND LOPT, I4, 4HARE, I4)
21 FORMAT(1X,10HSPARES FOR, I4, 4HARE, I4, 4HARE, I4, 4HAND, I4)
1001 FORMAT(1X,19HAVAIL AND COST FOR, I4, 4HARE, F8.6, 4HAND, F8.2)
1002 FORMAT(1X,20HAVAIL AND PCOST FOR, I4, 4HARE, F8.6, 4HAND, F8.2)
1003 FORMAT(1X,20HAVAIL AND NCOST FOR, I4, 4HARE, F8.6, 4HAND, F8.2)
1004 FORMAT(1X,20JOIN, 100 AND L.GE.99)
1005 FORMAT(1X,20JOIN.LE.99 AND L.GE.100)
1006 FORMAT(1X,20JOIN.GE.100 AND L.GE.100)
1007 FORMAT(1X,7JLOPT IS, I4)
1008 FORMAT(1X,19HJ.I, CSPRS(I,1) ARE, 3I4, F8.2)
1009 FORMAT(1X,3HJ.K,L, AVAIL(J,K) AND AVAILO(L) ARE, 3I4, 2F8.6)
1010 FORMAT(1X,19HCSPRS FOR OPT, I4, 10HAND SPARE, I4, 4HARE, I4, F8.2)
1011 FORMAT(1X,9HCSPRS = I4)
1012 FORMAT(1X,19HCSPRS(I,1) ARE, 3I4, 3I4)
1013 FORMAT(1X,19HNAV.SER(MAV) ARE, 3I4, 3I4)
1014 FORMAT(1X,28HJ.J,K,AV(JJ), CC(JJ), SP(JJ), 3I4, F8.6, F8.2, I4)
1015 FORMAT(1X,7HCOST= F8.2)
1016 FORMAT(1X,12HCHECK POINT I4)
1017 FORMAT(1X,7HMATV = I4, 15HAND SER(MATT) = I4)
1018 FORMAT(1X,29HJ.L, AVAILO(J), AVAILO(L) ARE I4, I4, 2F8.6)
1019 FORMAT(1X,33HAVAIL AVAILO(FJ), CSPRS(FJ,1) ARE, I4, F8.6, I4)
1100 FORMAT(1X,3HAVAIL OR SUBROUTINE HAS BEEN ENTERED)
1101 FORMAT(1X,4HSPARES COMPUTED-FIRST INPUT WAS STOP CODE)
1102 FORMAT(1X,4HINPUT FOR FIRST COMBINATION MUST BE 68)
1103 FORMAT(1X,3HHINVALID COMBINATION HAS BEEN INPUT)
1105 FORMAT(1X,24HJ.I AND CSPRS(J,1) ARE, 3I4)
1120 FORMAT(1X,7HHOLD = I4)
1121 FORMAT(1X,7HHOLD8 = I4)
END
APPENDIX D

TIGER PROGRAM OUTPUT EXAMPLES

The TIGER simulator produces both standard and optional outputs. The various options are discussed in Appendix B under the Printout Option Card. The optional output used for this research was the management summary printout. It first displays most of the user's input, the allowance determination model used to compute repair part allowances (if one was used), and the number of repair parts being used. An example of this output is shown in Table XVIII. A detailed explanation of the entries on Table XVIII is provided in Reference 4.

The TIGER simulator then prints a message every time the system goes down indicating which components are down and when they will come back up. An example of this output is shown in Table XIX. A detailed explanation of the entries on Table XIX is provided in Reference 4. Since this portion of the output was voluminous and not useful for analysis during this research, it was suppressed.

The TIGER simulator then prints the cumulative measures of effectiveness for the system after each group of 50 missions has been simulated. An example of this output is shown in Table XX. A detailed explanation of the entries on Table XX is provided in Reference 4. Since this portion of the output was voluminous and not useful until all simulations were completed, it was suppressed until the last mission simulation was completed.

The TIGER simulator then produces tables which summarize data about specific equipment failures, the number of repair parts used, and critical equipments. An example of this
output is shown in Table XXI. A detailed explanation of the entries on Table XXI is provided in Reference 4.

TABLE XVIII

Sample TIGER Model Output

<table>
<thead>
<tr>
<th>90 DAY .25 FLSIP EVALUATION OF SYSTEM Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>XXxxxxxxxxxxxxxxxxxxxx TIGER xxxxxxxxxxx</td>
</tr>
<tr>
<td>X NAVSEC 6112 Luetjen+Mandel+Vail+Alley+Brown XX</td>
</tr>
<tr>
<td>XNPS IBM/360 VERSION LT. J. LEATHER THESES 9/80XX</td>
</tr>
<tr>
<td>XAS AMENDED BY LDBR. P.J. O'REILLY THESES 12/81XX</td>
</tr>
</tbody>
</table>

RANDOM SEED IS 2222
1000 1000 1.00 1.26 2222 1
PHASE SEQUENCE TYPE DURATION CUM TIME
1 1 2160.00 2160.00
0 1.00 0.0 1.00 1.00

TYPE NAME MTBF MTTR DC ADT1 ADT2
1 ITEM A 1720.0 10.00 1.000 0.0 0.0
2 ITEM B 3000.0 10.00 1.000 0.0 0.0

TYPE EQUIPMENT
1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
3 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

SPARES WILL BE DETERMINED WITH MARGINAL ANALYSIS

BUDGET IS 850.

THE COST OF ITEM 1 IS 200.00
THE COST OF ITEM 2 IS 50.00
THE COST OF ITEM 3 IS 100.00
ALL SPARES HAVE BEEN COMPUTED

SPARES TYPE SHIP TENDER BASE FACTOR
1 1 0 0 0 0 0 999.00
2 1 0 0 0 0 0 999.00
3 2 0 0 0 0 0 999.00

154
| Column 1 | Column 2 | Column 3 | Column 4 | Column 5 | Column 6 | Column 7 | Column 8 | Column 9 | Column 10 | Column 11 | Column 12 | Column 13 | Column 14 | Column 15 | Column 16 | Column 17 | Column 18 | Column 19 | Column 20 | Column 21 | Column 22 | Column 23 | Column 24 | Column 25 | Column 26 | Column 27 | Column 28 | Column 29 | Column 30 | Column 31 | Column 32 | Column 33 | Column 34 | Column 35 | Column 36 | Column 37 | Column 38 | Column 39 | Column 40 | Column 41 | Column 42 | Column 43 | Column 44 | Column 45 | Column 46 | Column 47 | Column 48 | Column 49 | Column 50 | Column 51 | Column 52 | Column 53 | Column 54 | Column 55 | Column 56 | Column 57 | Column 58 | Column 59 | Column 60 | Column 61 | Column 62 | Column 63 | Column 64 | Column 65 | Column 66 | Column 67 | Column 68 | Column 69 | Column 70 | Column 71 | Column 72 | Column 73 | Column 74 | Column 75 | Column 76 | Column 77 | Column 78 | Column 79 | Column 80 |
### Table XX

<table>
<thead>
<tr>
<th>Reliability Phase 1: 1.1</th>
<th>Instant Availability</th>
<th>5.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability Up To Phase 1</td>
<td></td>
<td>5.5</td>
</tr>
<tr>
<td>Readiness</td>
<td>0.2154</td>
<td></td>
</tr>
<tr>
<td>Average Availability</td>
<td>0.6216</td>
<td></td>
</tr>
<tr>
<td>Instant Availability</td>
<td>0.7663</td>
<td></td>
</tr>
</tbody>
</table>

A grand total of 120 missions have been run.

The reliability is 5.5.

The lower confidence is 0.2.

The reliability is 5.2154.

The average availability is 0.6216.

The instant availability is 0.7663.

The mean time between mission failures is 472.5.

The LCL for MTBF is 293.9.

The MTDI variance variance is 196.431.

The system #1 is 416.3.

The system #1 is 854,958.

Another set of 5 missions will be run to obtain required statistical confidence.
TABLE XXI

Summary Tables

EQUIPMENT FAILURES AND CORRECTIVE MAINTENANCE SUMMARY

<table>
<thead>
<tr>
<th>EQUIP NO.</th>
<th>TYPE NO.</th>
<th>TOTAL EQUIP. FAILURES</th>
<th>AVG NO. FAILURES</th>
<th>AVG CM MANHOURS PER MISSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>782</td>
<td>2.607</td>
<td>312.800</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>583</td>
<td>1.943</td>
<td>97.167</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1365</td>
<td>4.550</td>
<td>409.967</td>
</tr>
</tbody>
</table>

AVERAGE NUMBER OF SPARES USED PER MISSION

<table>
<thead>
<tr>
<th>SPARES TYPE</th>
<th>STOCK USED</th>
<th>TENDER USED</th>
<th>BASE USED</th>
<th>USED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>2.56</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>1.90</td>
<td>0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

90 DAY .25 FLSIP EVALUATION OF MODEL SYSTEM

CRITICAL EQUIPMENTS
UNAVAILABILITY AND PERCENT OF UNAVAILABILITY

<table>
<thead>
<tr>
<th>NAME</th>
<th>NUM HRS</th>
<th>UNAVA PERCENT</th>
<th>EQU TYPE</th>
<th>EQU NUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEM A</td>
<td>86123.3125</td>
<td>0.1329</td>
<td>69.86</td>
<td>1</td>
</tr>
<tr>
<td>ITEM B</td>
<td>34262.5977</td>
<td>0.0529</td>
<td>27.79</td>
<td>2</td>
</tr>
</tbody>
</table>

90 DAY .25 FLSIP EVALUATION OF MODEL SYSTEM
CRITICAL EQUIPMENTS
UNRELIABILITY AND PERCENT OF MISSION FAILURES

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>FAILURES</th>
<th>UNREL PERCENT</th>
<th>EQU TYPE</th>
<th>EQU NUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEM A</td>
<td>171.5</td>
<td>0.5716</td>
<td>57.74</td>
<td>1</td>
</tr>
<tr>
<td>ITEM B</td>
<td>125.5</td>
<td>0.4183</td>
<td>42.29</td>
<td>2</td>
</tr>
</tbody>
</table>

TOTAL NO. MISSIONS = 300
TOTAL NO. MISSION FAILURES = 297
LIST OF REFERENCES


<table>
<thead>
<tr>
<th>No.</th>
<th>Copies</th>
<th>Distribution List</th>
</tr>
</thead>
</table>
| 1.  | 2      | Defense Technical Information Center  
          Cameron Station  
          Alexandria, Virginia 22314 |
| 2.  | 1      | Defense Logistics Studies Information Exchange  
          U.S. Army Logistics Management Center  
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| 3.  | 1      | Commanding Officer  
          Navy Fleet Material Support Office  
          Mechanicsburg, Pennsylvania 17055 |
| 4.  | 1      | Lieutenant Commander Howard Gorman, Code 93  
          Navy Fleet Material Support Office  
          Mechanicsburg, Pennsylvania 17055 |
| 5.  | 1      | Operations Analysis Department  
          Navy Fleet Material Support Office  
          Mechanicsburg, Pennsylvania 17055 |
| 6.  | 1      | Captain Morrow, Code 500  
          Navy Ships Parts Control Center  
          Mechanicsburg, Pennsylvania 17055 |
| 7.  | 1      | Mr. Bernard B. Rosenman  
          U.S. Army Inventory Research Office  
          Room 800, Custom House  
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          Philadelphia, Pennsylvania 19106 |
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          Department of Administrative Science  
          Naval Postgraduate School  
          Monterey, California 93940 |
| 10. | 5      | Professor F.R. Richards (Code 55Rh)  
          Department of Operations Research  
          Naval Postgraduate School  
          Monterey, California 93940 |
| 11. | 2      | Professor Alan W. McMasters (Code 54Mg)  
          Department of Administrative Sciences  
          Naval Postgraduate School  
          Monterey, California 93940 |
| 12. | 1      | Lieutenant Commander P.J. O'Reilly  
          874 Stanford Avenue  
          Chula Vista, California 92010 |
LME 83