A TRANSIENT STATE
MAINTENANCE REQUIREMENTS PLANNING MODEL/

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(ABSTRACT)

A model is developed for use by logistics planners in determining period by period maintenance requirements for repairable item populations. The model generates maintenance requirements with respect to manpower and facility requirements and spare parts requirements. The model is capable of capturing nonsteady-state failure behavior of populations of repairable items. Each item within the population is broken down into one or more families of components and subcomponents that can have different failure/repair characteristics. Probability of component failure may be generally distributed. A specific data requirement for the model is established. The model is structured to allow the user to conduct various "what if gaming" through an iterative procedure on a personal computer.
This research document includes a literature review that establishes a history of logistics modeling. The literature review provides impetus to the proposed research by defining a need for a transient state model for maintenance requirements planning. The model is validated by a case study involving the generation of maintenance requirements for a case population.
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The planning and management of logistics requirements for repairable item populations has become a monumental task as the size, complexity, and expense of such populations has increased. A repairable item population consists of units that, up to a point, are more economical to repair than to replace. Logistics for both military and civilian purposes has been referred to as "the study and application of decision making techniques intended to achieve efficient allocation and use of resources in satisfying stated objectives of an organization" [6]. As can be seen from this definition, a logistics planner has the responsibility for making decisions that can have impact on budgets and on the state of readiness of repairable item populations. To illustrate the significance of the logistics responsibility consider that in 1968, 52% of the total investment in spare parts by the Air Force was in repairable items, which at the time amounted to about ten billion dollars [31]. By 1975, the percentage had risen to about 65% [23]. Logistics decisions regarding inventory management, procurement, maintenance, and distribution must be made continuously in order to support any system containing repairable items.
In order to make effective logistics decisions in the face of complex logistics systems, planners need analysis tools that can help determine the maintenance requirements of recoverable item populations. The logistics planner needs a tool that provides him with these maintenance requirements prior to the procurement and deployment of recoverable item populations. Some data, provided by Air Force sources, suggest that "about 80% of the life time logistics costs of an aircraft is determined by decisions made before the aircraft begins to fly. These decisions relate to design tradeoffs of performance against reliability and maintainability, with resulting impact on maintenance manning, initial spare parts procurement, location of repair, and ground support equipment investment" [7].

In order to forecast the true maintenance requirements of a repairable item population, the maintenance requirements of the population during its entire life cycle must be forecast. This life cycle can include several stages that vary from population to population. The failure characteristics demonstrated by each member of the population may vary from stage to stage. If the failure characteristics of a population vary significantly from period to period then the total population maintenance requirements can vary significantly from one time period to
another.

Stage dependent failure characteristics are observed among many populations. An example would be populations that experience a "burn in" stage where the rate of failure for the initial period of usage is greater than for subsequent periods. Later on in the life cycle of the population, the failure rate again accelerates as the population ages and begins to "wear out". Other populations may exhibit a continuously accelerating failure rate over their life cycles. The point is that in many cases it is very difficult to establish an average failure rate that will generate accurate maintenance requirements on a period by period basis.

1.1. STATEMENT OF THE PROBLEM.

There are two basic problems with logistics models intended to serve as planning and analysis tools. First, logistics models do not evaluate the complete maintenance requirements of repairable item populations over the entire life cycle of the population items. Models have tended to focus on one particular maintenance requirement or another, by making simplifying assumptions about the other related maintenance requirements. One of the major simplifications made has been the assumption that systems operate in steady-state all of the time and that logistics requirements may be determined from these steady-state
conditions. Under this assumption, an average rate of failure is applied to the total population life cycle in order to generate maintenance requirements. Some populations never attain a steady-state of operation. This could be due to characteristics inherent in the components that comprise each member of the population, or due to external stimuli such as war conditions, temperature, moisture, or dust.

Logisticians such as Geisler and Murrie [7] and Kline [18] have called for the development of models that are useful during all phases of a population life cycle and are robust in that they address a broad range of maintenance requirements. These logisticians and others also allude to the second major problem with logistics models that exists today, and continues to exist after the completion of this research. This second problem pertains to the data requirements typically imposed by logistics models. In particular, to evaluate the multitude of maintenance requirements generated by a repairable item population, logistics models have generated extensive data requirements for failure and repair information that is not readily available.

1.2 OBJECTIVE.

The intent of this research is to develop the methodology for a logistics model that determines and
evaluates maintenance requirements of repairable item populations. The model is capable of generating maintenance requirements for the total life cycle, whether the repairable items are operating under steady-state or nonsteady-state conditions. The model allows the logistics planner to develop and evaluate the desired logistics system in the face of availability constraints, budget constraints, space constraints, procurement constraints, and personnel constraints. Development of the model has produced a data requirement. This data requirement is expounded upon. The results produced by the model emphasize what type of data base the logistician must have in order to field and operate a population at a reasonable cost and maintain the required degree of readiness.

The objectives of the research can thus be summarized within three major categories. They are as follows:

1. to develop a transient state model for describing the failure behavior of a population of repairable items that has the ability to
   a. capture nonsteady-state behavior
   b. model the failure behavior of a population of items where each item is comprised of one or more families of components and subcomponents that possess different failure/repair characteristics
c. model the flow of the population into repair facilities
d. evaluate system availability over time
e. specify the logistical consequences of alternative item quality (quality is described by the failure behavior of items) and item procurement policies

2. to generate maintenance requirements on a period by period basis with respect to
   a. manpower and facility requirements
   b. spare parts requirements

3. to establish the practicality of the model by
   a. providing the flexibility to conduct various "what if gaming" that is of interest to logisticians
   b. clearly establishing the specific data requirements of the model
   c. implementation of the model for a realistic case study.

1.3 OVERVIEW OF THE RESEARCH.

The remaining chapters of this research document contain a review of literature pertinent to logistics modeling, a discussion of the computational basis of the model developed, a discussion of the implementation of the model developed, case study documentation, and conclusions
and recommendations. A partial program listing is attached as an appendix. A list of referenced authors is included as a bibliography.

After a brief introduction, the literature review discusses logistics models by functional classification. An attempt has been made to discuss some of the earlier, prototype models in each classification and then to move forward in time, illustrating extensions made of prototype models and also new approaches that have been developed. The first classification described is "The Repair/Replace Decision". This classification includes models whose basic function is to determine when it is advantageous to repair units upon failure and when is is advantageous to replace a failed unit with a new unit. The second classification is "Determining Inventory Requirements". This classification discusses logistics models whose primary function is to evaluate either spares or spare part inventories required to support repairable item populations. The concept of spares versus spare parts is discussed in the literature review. The third classification is "General Logistics Models" that includes a discussion of logistics models that attempt to address a broad range of logistics problems rather than concentrate on specific areas. The fourth classification used is "Queueing Theory and Logistics". These models encompass a family of logistics models that
include queueing theory to determine the effects of finite capacity repair facilities on other logistics requirements. The literature review closes with a general discussion of the state of the art in logistics modeling and a summary.

In Chapter III, the discussion of the computational basis of the model opens with an introduction. This is followed by definitions of key terms used in describing the model. The development of the model is described with special emphasis placed on two major concepts applied during the research. The first of these concepts, the multi-stream concept, is basically the same as the nested Markov Chain concept proposed by Frisch [5]. The second concept involves the use of a typical population member bill of materials to establish a maintenance tree structure that is used to track specific component maintenance requirements. The description of the computational basis of the model continues with discussions of assumptions, parameters, decision variables, calculations, and measures of performance used. The flexibility of the model is exhibited through a discussion of possible uses of the model. Chapter III closes with information on limitations of the modeling approach and a summary.

Chapter IV opens with an introduction and continues with a profile of the data requirement generated by the model. The remainder of the chapter is concerned with
possible applications of the model in lieu of certain model limitations. Model limitations result from assumptions made and from physical limitations of computing facilities utilized.

The model is validated through a case study which is discussed in Chapter V. Due to the scarcity of failure and repair data, much of the data used for the case study is fabricated but is, in most cases, representative of a real population of Side Loadable Warping Tugs employed by the U.S. Navy. Also included in Chapter V are scenario descriptions for two additional case studies, designed to further exhibit the flexibility and "what if" gaming capabilities of the model.

The final chapter of this thesis contains conclusions resulting from the research conducted. The chapter closes with a list of recommended computer enhancements and research extensions relative to transient state modeling of maintenance requirements. An operator's guide and a listing of the computer program are included as appendices.
2.1 INTRODUCTION

In a survey of maintenance models, Pierskalla and Voelker [26], write that, "for two decades, there has been a large and continuing interest in the study of maintenance models for items with stochastic failure." This observation is substantiated not only in Pierskalla and Voelker's survey, but also in surveys of maintenance models conducted by Barlow and Proschan [2], McCall [21], Sherif and Smith [32], and Nahmias [23]. Additional sources such as Department of Defense bibliographies, an assessment of military logistic models by Geisler and Murrie [7], and reviews of related topics such as availability by Lie, Hwang, and Tillman [19] verify that papers written since the late 1950's concerning the maintenance of stochastically failing systems number well into the hundreds and probably over one thousand.

The maintenance of stochastically failing items can involve decisions regarding the repair or replacement of items, the determination of spare or spare part inventory levels, inspection and preventive maintenance policy, and the determination of repair facility characteristics. These decisions can be made under conditions of certainty...
where failure and repair rate probability distributions are known and related costs also are known. Uncertain conditions exist where some aspect of the maintenance model is not known. Besides unknown failure and repair distributions and unknown costs, there can be uncertainty associated with the determination of the state of a system through inspection or uncertainty regarding the state to which a unit is returned by repair. Models developed assuming certainty in the knowledge of model parameters are reviewed in this chapter.

Some of the models reviewed in this chapter have concentrated on a particular facet of the maintenance process and others have chosen to encompass many maintenance decisions. This literature review will move from specific maintenance models to the more generalized models that consider a broader scope of the logistics process.

2.2 THE REPAIR/REPLACE DECISION

Some of the basic decisions involved in the maintenance of any item are when to repair the item and when to replace the item. These decisions may be made at discrete time intervals or can be made on a continuous basis, that is, at any time on a continuous time axis.

Repair or replace decisions are important because of the impact they have on the entire logistics system. Kline
[18] writes that the repair or replace decision "impacts support resources (technician numbers, skill levels and training, spares and repair parts, facilities, test and support equipment, and maintenance information), as well as the specific maintenance actions to be taken and the levels at which repairs are made. The decision also affects such system and design attributes as safety, reliability, accessibility, and human factors." Repair or replace decisions are also going to have a specific impact on the life cycle cost of the system items themselves.

2.2.1 Basic Discrete Time Markov Process Model.
Pierskalla and Voelker [26] point out that most discrete time maintenance models are Markov decision models, in which the state of the system is described by the level of deterioration or the number of spare units available in inventory. They also go on to describe a model developed by Derman [3] as being the basic model for Markov process repair/replace models.

Derman's original model considers the inspection of a unit at discrete time intervals with the unit being observed to be in a particular state of deterioration. Each time interval represents a step in a Markov chain. The user of the model has two options: take no action or replace the unit. If no action is taken there are corresponding probabilities of transitioning from the
presently occupied state to any state of further deterioration in one period. If the unit is replaced, then the unit immediately returns to state 0 and the transition probabilities for state 0 again apply. The only way to return to state 0 is through replacement, otherwise the unit continues to deteriorate toward complete failure. The transition probabilities that make up the deterioration process Markov chain are steady-state probabilities.

2.2.2 Discrete Time Semi-Markov Processes.
Generalizations of the basic Derman model have accounted for a great number of subsequent repair/replace maintenance models. One reason that Derman's model was generalized was that the model does not illustrate that the probability of moving into a less desirable state changes with time. The steady-state assumption and the use of a single Markov chain prevent this consideration. Kao [17] and Hayre [13] utilized a discrete time semi-Markov process to overcome this problem. The semi-Markov process is described in Barlow and Proschan [2, pages 131-139] and Ross [28, chapter 7].

In a semi-Markov process, transitions from state to state are made in accordance with a Markov chain similar to the chain used by Derman. The time spent in each state before a transition occurs is a random variable dependent on the state presently occupied. By using these random
variables in conjunction with the Markov transition probabilities, Kao and Hayre determine an expected time of occupancy for each state. By associating the expected occupancy time with known costs of occupancy, a cost figure analogous to a repair cost is developed. Comparison of this cost with a known cost to replace a unit allows the user of these semi-Markov models to determine at what stage it becomes more advantageous to replace instead of repair. Both authors assume that the failure stage is inevitable.

2.2.3 Continuous Time Models. Continuous time repair or replace models assume that the actions of the decision maker may potentially take place anywhere on the continuous time axis. Some continuous time models permit the maintenance activity to occur as a continuous stream. In this type of situation, the decision maker must optimize over the function $m(t)$, where $m(t)$ is the maintenance expenditure rate at time $t$. A review of the literature reveals that these types of models, called control theory models by Pierskalla and Voelker [26], appear to have been developed primarily for commercial use because parameters such as production revenues and sale date are considered. The control theory models could be generalized to apply to commercial, government, and military situations. For example, the sale date parameter is analogous to retirement age. Instead of maximizing production revenue, total life
cycle costs could be minimized.

A model developed by Sethi [30] is an example of a control theory model. Sethi's model allows the consideration of the machine replacement problem in a changing technological environment where replacement machines may cost different amounts and possess different production and maintenance characteristics. Sethi considers an infinite chain of machines, where each link in the chain represents a uniform length replacement cycle with identical preventive maintenance. The objective is to maximize the present value of all future net profits from the chain of machines. In order to obtain the present value, the following continuous functions are employed by the model: \( P(t) \), the production rate at time \( t \); \( E(t) \), the ordinary maintenance; \( S(t) \), the salvage value; \( m(t) \), the preventive maintenance rate; \( C(T) \), the cost of a machine purchased at time \( T \); and \( d(t) \), the obsolescence function at time \( t \) in terms of dollars subtracted from \( S(t) \). Decision variables are the length of the replacement cycle, \( T \), and the schedule of preventive maintenance, \( m(t) \). When the preventive maintenance rate, \( m(t) \), increases, Sethi assumes that \( P(t) \) increases, \( E(t) \) decreases, and \( S(t) \) increases. The problem is solved using a nonlinear programming method.

A second category of continuous repair or replace models, as defined by Pierskalla and Voelker [26], are age
replacement models. These types of models introduce the concept of age dependent operating costs to the traditional repair or replace models. An important model of this type was developed by Barlow and Hunter [1]. Through this model, they introduced the concept of minimal repair, which is the idea that the failure of a single component of a system does not call for system replacement, but rather a repair that does not affect the system's failure rate.

Barlow and Hunter assume that the system failure rate corresponds to a failure distribution with a density parameter. It is further assumed that replacement or overhaul occurs at times $T, 2T, 3T, \ldots$. The objective of the model is to select $T$ so as to minimize

$$C(T) = \lim_{t \to -\infty} \frac{c_1 EN_1(t) + c_2 EN_2(t)}{t}$$

where $c_1 = \text{cost of minimal repair}$, $c_2 = \text{cost of replacement}$, $EN_1(t) = \text{expected number of failures in } [0,t]$, $EN_2(t) = \text{expected number of replacements in } [0,t]$, $C(T) = \text{operating cost}$.

2.3 DETERMINING INVENTORY REQUIREMENTS

Nahmias [23] states that most classical inventory models assume that units are completely consumable, i.e. not repairable. Logisticians cannot afford to take this point of view. In a paper published in 1967, Schrady [29] estimated that the Navy's investment in repairable units was approximately 58% of their total dollar investment in
inventory. It can only be assumed that this percentage has remained steady or increased as inflation and other costs have boosted the price of new units. Nahmias points out that generally it is the high value items that are more economical to repair than to replace. One result of the large number of repairable items in use is that there are situations, especially in the military, where being able to determine inventory requirements for spares and spare parts to repair these items can be of significant economical advantage.

As an example of the cost effectiveness of managing inventory levels, consider the military's stockage of spare parts for aircraft repair. Since aircraft are very expensive it follows that repair parts would be expensive also. If inventory requirements for the parts are not established through some analytical means, it is conceivable that logisticians may overstock repair parts, resulting in a large and unnecessary investment in parts and storage space. If, on the other hand, parts were understocked and shortages occurred, expensive aircraft and skilled pilots would be grounded and unable to carry out possible crucial missions.

In addition to economic reasons, an appropriate inventory level must be maintained to meet availability constraints often imposed in both commercial and military
settings. When understocking occurs, key equipment could be down during either crucial production periods or during a military operation. Nahmias' review [23] reveals that many maintenance models have been developed exclusively to provide spare and spare parts inventory levels and other models have included inventory level determination as one of several maintenance outputs.

Nahmias evaluates two basic types of inventory models, continuous review and periodic review models. The continuous review models assume that demands for spare parts can occur at any instant in time. As a result of this approach, Nahmias states that the majority of the continuous review models use a one for one ordering policy, i.e., when a unit is shipped to the repair facility an order is simultaneously placed for a spare unit or a particular spare part. Periodic review models assume that inventory levels are reviewed periodically and that total demand in a period is a random variable with some specified distribution function and density.

Before going further, a brief discussion of terminology is called for. The word "spare" will be used to denote the number of additional, complete end items that will be kept in inventory. Generally, a spare is ready for use immediately upon failure of an identical unit. "Spare parts" denote additional components kept in inventory.
These components are used to repair end items that require repair.

Level of "indenture", as described by Nahmias, refers to the relationship between an end item and its components or modules. For example, an end item could consist of several modules each of which has its own spare parts requirements. The end item represents a level of indenture, the modules a second level of indenture, and the spare parts for the modules a third level of indenture.

The term "echelon" will apply to the levels of repair available for use by repairable items. As an example, consider an end item that could be repaired at a base facility if one type of failure occurred, or would require repair at a centrally located depot if another type of failure occurred. In this case there are two echelons or levels of repair.

2.3.1 Repairable Spares Requirements, Single Indenture Analysis, Continuous Review. An important inventory model, that according to Nahmias has served as a basis for some of the small number of multi-echelon inventory models that have actually been implemented, was the METRIC model developed by the RAND Corporation and reported by Sherbrooke [31]. METRIC is a two echelon, single indenture model that allows the user to determine inventory requirements for spare end items. METRIC seeks
to minimize the number of backorders of end items within a given budget constraint. A stationary compound Poisson probability distribution describes the demand for spares. Muckstadt [22] notes that a predictable nonstationary distribution for demand could be used.

Input data required by the model includes average base and depot repair times for each item, unit costs, certain probability distribution parameters, Not Repairable This Station (NRTS) rates, and average order and ship times. Additional assumptions include: there is no lateral supply between bases, there are no condemnations (all failed parts are repaired), repair times are statistically independent, there are infinite queues at repair channels, repair level depends only on repair complexity, items are equally essential, and a failure of one type is statistically independent of another type.

Porteus and Lansdowne [27] consider a single indenture model in which they investigate stochastic failures that can be one of several types. The particular type of failure is governed by a probability distribution. Failures are assumed to occur according to a simple Poisson process. The system is assumed to be operating in steady-state. When an end item fails, it is assumed to be replaced by a spare end item if one is available, otherwise a shortage occurs. Expected repair times are considered as
decision variables. Different expected repair times are associated with different types of failures.

Through an optimization procedure that utilizes a Lagrangian approach, Porteus and Lansdowne minimize expected weighted shortages of all items at all locations given a budget constraint. The weights assigned to shortages are based on item essentiality. The costs constrained by the budget include the cost of implementing an expected repair time and the cost of stocking spares.

2.3.2 Spare Parts Requirements, Multi Indenture Analysis, Continuous Review. As stated in Nahmias, the METRIC model itself has not been implemented. However, extensions of the model were in use by the Air Force in 1981. One primary enhancement to the model was the addition of multi-indenture capabilities.

2.3.2.1 Steady state evaluation. As evidenced by this literature review and as noted by reviewers such as Geisler and Murrie [7], the great majority of existing maintenance models assume that the demand for spares or spare parts is in steady-state. Murrie and Geisler and Kline [18] note that this assumption is also true of extensions of the METRIC model that the Air Force has implemented.

One of the extensions of METRIC, that was in use by the Air Force in 1981, is MODMETRIC reported by Muckstadt
MODMETRIC extends METRIC to include a multi-indenture analysis. Muckstadt considers two levels of indenture, the end item and its components. The model may be extended to consider additional levels of indenture. Muckstadt considers the fact that backorders of spare parts for components do not necessarily carry the same penalty as backorders for components themselves. Otherwise, MODMETRIC makes the same assumptions and produces similar output as METRIC.

Graves and Keilson [8] developed a single echelon, two indenture inventory model. Their model differs from the METRIC concept in that they consider a finite repair facility and use system availability and system persistence as performance measures. System persistence is measured by the time until the next system failure. The two indentures evaluated are the end items and critical modules.

Graves and Keilson assume that each end item requires exactly one unit of each module to be operable, complete cannibalism of the inventories of repairable modules is allowed, the failure and repair of distinct types of modules are independent, and each random variable representing the state of the modules can be modeled as a stationary birth-death process. Also, it is assumed that the mean time between system failures follows an exponential distribution. It is assumed that the end items
operate as a system (like a squadron of aircraft) and that system failures are rare.

Besides determining appropriate inventory stockage levels for repairable modules, Graves and Keilson illustrate economic benefits that would occur with improved repair capability or improved module reliability. The economic benefits are determined through the use of cost functions specific to the individual repairable modules.

It should be noted that this model, along with the other inventory models discussed thus far, considers a series relationship between failures of lower levels of indenture versus the failure of the end item, i.e. when a component fails, the entire end item is considered to be in failure. When a series relationship between components exists, failures of components that do not result in end item failure do not occur. An alternate arrangement, not mentioned thus far, is a parallel relationship between failures of lower levels of indenture versus the failure of the end item. In this type of situation there may be redundant component parts where the failure of one component does not cause the failure of the end item.

2.3.2.2 Transient state evaluation. Hillestad [14] presents a model, DYNA-METRIC that will evaluate transient state demand for aircraft spare parts. This model also is an extension of the METRIC model. Hillestad's model is a
multi-echelon, multi-indenture model that can evaluate series and parallel systems. The rate of demand for spare parts is Poisson. In place of a constant repair time, the model uses a repair function which is the probability that a component entering repair at time $s$ is still in repair at time $t$. Hillestad defines the daily demand rate $d(t)$ under transient conditions to be:

$$d(t) = \text{(failures per flying hour)} \times \text{(flying hours/sortie at time } t) \times \text{(number of sorties per day per aircraft at time } t) \times \text{(number of aircraft at time } t) \times \text{(quantity of the component on the aircraft)} \times \text{(percentage of aircraft with the component)}$$

Under Hillestad's definition of the transient state, the failures per flying hour remains constant. DYNA-METRIC's measure of performance is aircraft availability. An infinite queue at the repair channels is assumed.

2.3.3 Periodic Review. The prototype periodic review model for a repairable item inventory is due to Phelps [25]. In that model, each stage of the review has two state variables: the amount of serviceable stock on hand and the amount of repairable stock on hand. Serviceable stock includes items that have been repaired or procured from outside sources and repairable stock includes items that are yet to be repaired and returned to service. An expected demand for spares per period must be provided by
the user of the model.

The user of the model utilizes two decision variables; the number of serviceables and the number of repairables on hand after all decisions have been made. The decisions that must be made at each stage require the specification of: the number of items to procure from outside, the number of repairables to repair, and the number of repairables and/or serviceables to scrap for salvage. Utilizing the results of these decisions, the model maximizes the total expected return in a single period.

2.4 GENERAL LOGISTICS MODELS

There are a few models in existence that provide the logistician with information on a broad scope of logistics problems, from repair or replace decisions to spare parts requirements. Following are descriptions of two of these models.

2.4.1 Level of Repair Model, Constant Failure Rate.

A group of extended repair or replace models that appear to be more general in nature are the level of repair models used by the military. In 1981, Kline [18] wrote that each of the three major branches of the military had their own level of repair models in operation. According to Kline, the level of repair models base their decisions at least partly on costs just as the other repair or replace models do. The level of repair models are more general than other
repair or replace models because they also determine where a repair should be made, where spare parts should be located, how many spare parts should be at each location, and the costs associated with these policies.

A paper by Jensen [16] illustrates some of the facets involved with optimum repair level analysis. Jensen evaluates equipment that can be broken down into repairable modules. His analysis is a multi-indenture, two echelon analysis that combines a family of more specific models into one large level of repair model to determine the optimum maintenance and logistics policies for the parts, modules, and higher modular assemblies in the face of an availability constraint. Optimum maintenance policy is defined with respect to when to repair and when to replace. Optimum logistics policy is defined with respect to where to repair and where and in what quantities to keep spare parts. Jensen's model also determines which parts are line replaceable. Line replaceable means that the end item or higher modular assembly does not have to be sent to a repair facility if a line replaceable part fails.

Jensen develops a method for classifying maintenance and logistics policies. There are three possible logistics policies: spare at the organization level, spare at the field level, or spare at the depot level. There are four possible maintenance policies: repair at either the
organization, field, or depot level or discard. Life cycle costs associated with these policies are determined by assigning a particular cost to each possible alternative for each element that makes up the life cycle costs. The optimal maintenance and logistics policy, taking into account the availability constraint, is determined through an enumerative scheme where each possible policy alternative is evaluated.

Some of the assumptions utilized in this level of repair model include: components of the equipment fail independently and randomly with a constant failure rate over time, the number of failures in a cycle time has a Poisson distribution, and the modules and their parts are in a series arrangement. Spares levels are determined using a Lagrangian approach.

2.4.2 A Stochastic Model. Frisch [5] provides the framework for the development of a periodic review model that not only determines inventory requirements but would allow the logistician to make repair and replace decisions. The construction of Frisch's conceptual model is unique in that it models the units of a repairable item population as a series of nested Markov Chains. If a population is made up of cohorts or units that are of different ages because of procurement practices or for other reasons, then each age group has its own failure characteristics at a given
point in time. Frisch accounts for the different failure characteristics by modeling each group of age cohorts as a separate stream or Markov Chain, thus resulting in the nested Markov Chains. See Figure 2.1 for an illustration of the nested Markov Chain concept.

The Markov Chains are driven by the mortality rate or the failure rate of the units. The Markov process used by Frisch is stationary in time. Barlow and Proschan [2, page 122] describe a stationary Markov process as follows:

In a Markov Chain, a conditional probability (called a transition probability) of a transition at time \( n \) for each pair \( i, j = 0,1,2,\ldots,m \) from state \( i \) to state \( j \) must be given. This probability is denoted by

\[
p_{ij}^{n,n+1} = P[X(n+1) = j \mid X(n)=i].
\]

The Markov process is stationary if the transition probability functions depend only on the time difference, that is,

\[
p_{ij}^{n,n+1} = p_{ij}^{0,1} = p_{ij}
\]

The Markov process utilized by Frisch is also a discrete time process in that the chain is indexed by time.

A discrete time, stationary Markov process, such as the one employed by Frisch, transitions until eventually a steady-state is reached. The Frisch model can evaluate the transition phase leading to steady-state conditions. This transition phase is analogous to the build up phase experienced between the time a population is first fielded and the time that full population size is attained. Frisch does assume, however, that his population operates in
# units surviving

\[ A_0, B, C_1, B_2, D_3, D_4, D_5 \]

# units procured

\[ A_0, A_1, A_2, A_3, A_4, A_5 \]

total # units in system

\[ A_0, B + A, C_1 + A_2, D_3 + A_4, D_4 + A_5, D_5 + A_6 \]

\[ A_n, B_n, C_n, D_n = \text{stream of units} \]
\[ t_n = \text{time period} \]
\[ \alpha_n, \beta_n, \gamma_n = \text{survival rates} \]
\[ G = \text{age group} \]
\[ A_n, B_n, C_n, D_n = \# \text{units in each age group} \]
\[ A_n = \text{units are procured at the end of each time period} \]

**FIGURE 2.1.** NESTED MARKOV CHAIN CONCEPT MULTI-STREAM MODEL
steady-state the majority of the time. Frisch also notes that within the Markov chains, number of operating hours or some similar parameter may be used in lieu of age when describing the state of the units.

By applying the failure probabilities to the respective number of cohorts in a particular age group, the expected requirement for spares may be determined for the period of time that each step of the Markov process represents. The model would have to either be extended to multiple indentures or applied to spare parts individually in order to determine "spare parts" requirements as Frisch alludes to in the title of the paper. By computing spares requirements, the model is providing the logistcian with a forecast that can be used for maintaining spares or spare parts inventories and a forecast that can be used to determine when it will be economically advantageous to replace rather than repair.

The Frisch model is not an optimization process but rather a "what if" model that allows the determination of the effects of two decision variables on the logistics system. The two decision variables are quality and mode of fielding.

Frisch notes that quality is hard to quantify. As a means of measuring quality, he suggests that performance (P) and quality (Q) can be measured with the same
dimension. Performance is defined as the output of a machine at its design point. Quality is defined by the delta ($\Delta$) or loss of output of a machine during its operation time, so $P - \Delta_t = Q_t$. The critical quality ($Q_c$) is defined as the limit to which the performance can deteriorate without rendering the machine useless for its mission. Frisch implies with this definition that only if two machines have identical design parameters can they be qualitatively compared. Thus, a qualitative comparison between functionally similar but not identical units can be accomplished by comparing the failure rates and the resulting repair costs of the respective units.

The mode of fielding has to do with the method with which a population is built up. Different modes of fielding could be as follows: procure all units in the first year; procure an equal amount of units each year (plus replacements for failed units) until the population reaches full size; procure a decreasing amount of units each year (plus replacements for failed units) until the population reaches full size; and so forth.

Frisch evaluated the effects of the two decision variables on the logistics system. His findings are summarized in Table 2.1. Findings 2, 3, and 4 are illustrated by the following example. Assume that the task of the logistician in this example is to make an initial
### TABLE 2.1. EFFECTS OF DECISION VARIABLES, FRISCH MODEL

<table>
<thead>
<tr>
<th>DECISION</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) no decision allowed</td>
<td>Logistics requirements have been determined, no total life cycle cost minimization is possible.</td>
</tr>
<tr>
<td>2) mode of fielding = block procurement</td>
<td>Support requirements will fluctuate.</td>
</tr>
<tr>
<td>3) block procurement and high quality</td>
<td>The span between support requirement fluctuations will increase with quality and the rate at which support requirements reach steady-state will decrease as quality increases.</td>
</tr>
<tr>
<td>4) block procurement and low quality</td>
<td>The span between support requirement fluctuations will decrease as quality decreases, however, support requirements will reach steady-state more rapidly as quality decreases.</td>
</tr>
<tr>
<td>5) quality and mode of fielding other than block procurement</td>
<td>System support requirements decrease as quality increases. Also, it is possible to build up systems of any desired quality with steady-state support requirements from the beginning.</td>
</tr>
<tr>
<td>6) mode of fielding and quality</td>
<td>Both decision variables affect total systems life cycle cost.</td>
</tr>
</tbody>
</table>
block procurement of 100 units and then maintain a population size of 100 from that time forward. Procurements may be made at the start of each year. The population has an annual survival rate of .9 and if a unit lasts for four years, it is retired from service at that time. See Figure 2.2 for a diagram of the nested Markov chains that represent this population.

The logistician in the example looks ahead 20 years and calculates the amount of units that will have to be procured each year in order to replace failed units and maintain the population size of 100. The yearly procurements are as follows:

<table>
<thead>
<tr>
<th>Year</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>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>100</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>76</td>
<td>17</td>
<td>17</td>
<td>18</td>
<td>60</td>
<td>21</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>22</td>
<td>22</td>
<td>50</td>
<td>23</td>
<td>25</td>
<td>26</td>
<td>42</td>
<td>26</td>
<td>26</td>
<td>28</td>
<td>37</td>
</tr>
</tbody>
</table>

Notice the large procurement amounts occurring at years 1, 5, 9, 13, 17, and 21. These peaks will generate corresponding peaks of support requirements, meaning that the demand for warehousing, maintenance work, and distribution will be uneven having its peak times and its slow times. See graph a. in Figure 2.3. This graph clearly shows the peaks and valleys that occur due to block procurement practices. When extended over a period of many years, a steady-state is reached where annual procurements and the corresponding support requirements become the same
### Figure 2.2. Nested Markov Chain Example

<table>
<thead>
<tr>
<th>t₀</th>
<th>t₁</th>
<th>t₂</th>
<th>t₃</th>
<th>t₄</th>
<th>t₅</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>72</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>G-4</td>
<td></td>
<td></td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>81</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>G-3</td>
<td></td>
<td></td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>90</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>G-2</td>
<td></td>
<td></td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>G-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **# units surviving**
  - t₀: 100
  - t₁: 90
  - t₂: 90
  - t₃: 89
  - t₄: 24
  - t₅: 83

- **# units procured**
  - t₀: 10
  - t₁: 10
  - t₂: 10
  - t₃: 11
  - t₄: 76
  - t₅: 17

- **Total # units in system**
  - t₀: 100
  - t₁: 100
  - t₂: 100
  - t₃: 100
  - t₄: 100
  - t₅: 100

- tₙ = year n
- Survival rate = 0.9 throughout each stream
- Surviving units are retired after four years of operation
- G-1 = 1st year of operation
- G-2 = 2nd year of operation
- G-3 = 3rd year of operation
- G-4 = 4th year of operation
FIGURE 2.3. BLOCK PROCUREMENT FLUCTUATIONS
from year to year.

Graph b. in Figure 2.3 represents the effects of quality on block procurement. When the quality, as represented by the annual survival rate of the population, is lowered to .7, steady-state is reached sooner than in the case where the survival rate was .9. Another result of the decrease in quality is that the peaks during the transient phase are lower, but the steady-state value eventually attained is higher than the steady-state value for annual procurements for the population with the .9 survival rate. This higher steady-state value translates to a greater annual support requirement. Note also that the lower quality units reach steady-state sooner than the higher quality units.

Frisch notes that an example such as this illustrates that

1) Low quality tends to promote constant replacement rates in the early stage of a system and hence may need little warehousing.
2) High quality is detrimental to a stabilization of the system and hence detrimental to economic replacement-production; it also requires high warehousing efforts.

Frisch also demonstrates the effects of uncertainty on support requirements and on repair/replace decisions. His
model allows for the evaluation of the trade-off of costs for testing to obtain more certainty versus the costs of operating a logistics system under uncertainty. Frisch states that a result of this trade-off evaluation is that it becomes apparent that under conditions of complete certainty a system should be repaired until it ceases to perform to standards. If uncertain conditions are present, then a point is reached where the total system's life cycle cost can be reduced by replacing instead of continuing to repair units. Other models contradict Frisch in that they can be used to illustrate that there are situations where certainty exists, but a point prior to the occurrence of unsatisfactory performance is reached where it is more economical to replace rather than repair.

A model by Fabrycky and Hart [4] illustrates this contradiction. Fabrycky uses his finite population queueing model to work an example that optimizes the replacement age. His example illustrates that a point can be reached where the costs of maintaining and operating an older unit exceeds the costs involved with purchasing a newer unit. This phenomenon occurs because Fabrycky assumes that the failure rate follows a bathtub function where the rate of failure begins to increase with age after a certain time. It is also assumed that mean times to repair increase with age. The combined effect of these
assumptions is that at some point, repair costs begin to increase with age until eventually these costs exceed the cost of purchasing and operating a new unit in place of the aging unit. Even at this point where a new unit becomes more cost effective, the old unit is still performing satisfactorily.

Frisch also illustrates that assuming there is in-house production capability, his model may be used for the evaluation of the production rate of spares or spare parts. The demand for spares or spare parts is of course determined by the nested Markov Chain model. By associating a penalty cost with shortages, the trade off between shortage costs incurred and costs saved by evening out production of spare parts may be evaluated. The same evaluation could be made by substituting costs saved by evening out procurement of inventory items for saved production costs.

Frisch closes his paper by pointing out that his model is flexible and extendable to cover large populations composed of many different cohort age groups. The model also may be extended to handle composite streams, where each stream within the nested Markov Chain can have a totally different probability distribution of failure and/or a different life expectancy.
2.5 QUEUEING THEORY AND LOGISTICS.

Of the models discussed thus far, that have considered repair times, a constant mean repair time has been assumed, independent of the state of the system, for items entering service. The models have not considered the queue that occurs when items are waiting for service. In most real life cases, where repair channel capacity is not infinite, the true time to repair is dependent upon the number of units queued up at the repair facility. Also, the failure rate of a population of units is dependent on the number of operable units. Unless an infinite number of spares is assumed, the number of units queued up at the repair facility must be known in order to calculate the number of operable units. In order to determine more exactly the time to repair and the failure rate, a class of maintenance models utilizing queueing theory have been developed.

These queueing models have the potential to consider perhaps the broadest scope of logistics problems because not only can repair or replace decisions or spare parts inventory level decisions be made, but now the actual operation of the repair channels can be studied. The application of queueing theory allows the logistician to determine the effects of repair and replace decisions on the operation of the repair channel. Queueing theory also provides the logistician with a means of more accurately
evaluating the effects of repair facility design on the total logistics system.

2.5.1 Queueing and the Repair/Replace Decision. Nahmias [23] writes that one approach for analyzing the queues that form at repair channels is through the classic machine repair model. Also, Nahmias points out that the original application of the machine repair model to the problem of determining suitable levels of spares inventory appears to be due to Taylor and Jackson [33]. The classic machine repair scenario as utilized by Taylor and Jackson supposes that $M$ machines operate continuously and are supported by $S$ spares. When a failure occurs, the item enters a repair facility and queues up for service. If available, a spare immediately replaces the failed item. The repair facility is assumed to consist of $r \geq 1$ parallel servers that repair units on a first come first serve basis.

Taylor and Jackson assume that the items become unserviceable at random, but they utilize a constant average rate of failure. They use a birth/death process in conjunction with the failure rate and they assume that when fewer than $M$ machines are operational, all machines cease to operate. From this assumption a stationary distribution of the number of machines in the repair queue under steady-state conditions is derived. The model then
considers the probability that a total breakdown in the system will occur as a function of the number of spare machines.

Gross and Harris [9, page 123] extended the classic machine scenario further and developed expressions for the expected rate of failure and the expected rate of repair dependent on the number of units in the repair system (queue plus repair channels). Their expressions apply only when the rate of failure and the time to repair are distributed exponentially with the respective parameters $\lambda$ and $\mu$.

The expressions developed are as follows. The state of the system, $n$, corresponds to the number of machines in the repair system so that, if $\lambda_n$ is the failure rate when the state of the system is $n$, then

$$
\lambda_n = \begin{cases} 
M \lambda & \text{if } 0 < n < S, \\
(M - n + S) \lambda & \text{if } S \leq n \leq M + S.
\end{cases}
$$

Let $u_n$ be the rate at which units leave the repair facility when the system state is $n$, then

$$
u_n = \begin{cases} 
n \cdot u & \text{if } 0 < n < r, \\
r \cdot u & \text{if } r \leq n.
\end{cases}
$$

2.5.2 Queueing and Repair Facilities. Hart [12] and Fabrycky and Hart [4] extend the machine repair model concept. Utilizing finite source queueing theory, they developed an acquisition/maintenance model that allows the
user to design an optimal cost system by specifying the values for certain decision variables. These decision variables include the population size, the replacement age of units, and the number of repair channels. The model also evaluates a second scenario where the mean time between failure and the mean time to repair are considered to be design variables. The model is a single indenture, single echelon model. The performance of the model is measured by comparing the total annual equivalent costs generated by different design scenarios embracing three general costs:

1. population annual equivalent cost which represents the cost of ownership of the population by evaluating acquisition cost of the unit, salvage value of the unit, and the interest rate.

2. repair facility annual equivalent cost which represents the cost of owning and operating a repair facility by evaluating the first cost of the facility by channel, the salvage value of the facility per channel, and the yearly administrative, labor, and overhead cost per channel.

3. out of operation or down cost which represents the cost of not having enough units operable to meet the demand.

Fabrycky and Hart employ a birth-death process that evaluates only the steady-state phase of operation of the finite population of units. They assume that the inter-arrival times of units for repair are exponentially distributed as are the times for repair. The arrival times are statistically independent of the repair times. The
exponential distributions are utilized for two reasons. First, a distribution that will produce a constant mean is necessary in order to allow the evaluation of steady-state conditions. Secondly, a distribution that "forgets" is required in order to be used with a birth-death process which has the Markovian property of "forgetfulness".

The meaning of "forgets" may be illustrated by the following, as taken from Hillier and Lieberman [15, page 325]:

"If the random variable $T$ is the length of time a process continues before an event occurs, and it has an exponential distribution, then

$$P[T > t + \Delta t \mid T > \Delta t] = P[T > t]$$

for any non-negative quantity $\Delta t$, thus, the process "forgets", in effect how long it has been going."

Just as in the machine repair problem, Fabrycky and Hart assume that repair channels operate in parallel and serve units on a first come first serve basis. (See Figure 2.4 for a diagram representing the relationship of the repair channels to the rest of the system.) Each repair channel has the same capability and only one unit at a time is repaired per channel. Fabrycky and Hart recognize that a population can consist of different aged units, thus at any given point in time the mean time between failure and the mean time to repair varies for each age group. It is
FIGURE 2.4. FINITE POPULATION SYSTEM
assumed that the population consists of an equal number of each age group. As shown in Figure 2.4, when a unit reaches the designated age of replacement, that unit leaves the population and a new unit is procured in its place and added to the population.

In the model, units that have been repaired return to the population with the same operational characteristics of their age group. The time spent in repair is the time elapsed from the instant the unit fails until the instant that the unit becomes operational again.

In order to calculate the amount of time a unit spends down, Fabrycky and Hart obtain the expected values for the MTBF and MTTR of each age group and utilize finite queueing theory to determine the expected time that a unit waits in the queue for repair, $W_q$, and the expected number of units in the repair system (queue plus repair
channels), R. The following queueing equations from White, Schmidt, and Bennett [35] were used:

\[ W_q = \frac{\sum_{n=C}^{n-1} \frac{n-C+1}{C^u} \frac{(N-n)}{(N-n)!} \frac{N!}{C^u} \frac{C^C(\lambda/uC)^n}{C!}}{\sum_{n=0}^{C-1} \frac{(N-n)}{n!(N-n)!} \left( \frac{\lambda}{u} \right)^n + \sum_{n=C}^{N} \frac{(N-n)}{(N-n)!} \frac{N!}{C^u} \frac{C^C(\lambda/uC)^n}{C!}} \]

\[ R = N \left[ 1 - \frac{1/u + 1/\lambda}{1/u + 1/\lambda + W_q} \right] \left[ 1 - \frac{1/u}{1/u + 1/\gamma} \right] \]

where:
- \( N \) = total number of items in population
- \( C \) = total number of repair channels
- \( \lambda \) = the arrival rate = 1/MTBF
- \( u \) = the service rate = 1/MTTR

Knowing the amount of time that units are out of service allows the calculation of the number of units down, which in turn makes the calculation of the out of operation or down costs possible.

A limited source queueing model by Hillier and Lieberman [15, page 311-312], provides an alternate method of calculating the expected number of units down. They assume a finite source population and exponentially distributed failure rates (1/\( \lambda \)) and service times (1/\( u \)). The queueing model has multiple, parallel servers, each with identical service capability. The resulting model is
a special case of the birth-death process such that

\[ \lambda_n = \begin{cases} (M-n)\lambda, & \text{if } n < M \\ 0, & \text{if } n \geq M \end{cases} \]

and

\[ u_n = \begin{cases} nu, & \text{if } 0 < n < s \\ su, & \text{if } n \geq s. \end{cases} \]

Hence,

\[ P_n = \begin{cases} P_0 \frac{M!}{(M-n)!n!} \left( \frac{\lambda}{u} \right)^n, & \text{if } 0 < n < s \\ P_0 \frac{M!}{(M-n)!s!s^{n-s}} \left( \frac{\lambda}{u} \right)^n, & \text{if } s \leq n < M \\ 0, & \text{if } n \geq M, \end{cases} \]

where

\[ P_0 = \left[ \sum_{n=0}^{s-1} \frac{M!}{(M-n)!n!} \left( \frac{\lambda}{u} \right)^n \right]^{-1} + \sum_{n=s}^{M} \frac{M!}{(M-n)!s!s^{n-s}} \left( \frac{\lambda}{u} \right)^n. \]

Finally,

\[ L_q = \sum_{n=s}^{M} (n-s)P_n. \]

where:
- \( M \) = total number of units in population
- \( s \) = number of servers or repair channels
- \( \lambda \) = failure rate
- \( u \) = service rate
- \( P_0 \) = probability of no units down
- \( P_n \) = steady-state probability of \( n \) units down
- \( L_q \) = expected number of items in the queueing system

Gross, Kahn, and Marsh [11] present a queueing model where infinite instead of finite queueing theory is utilized. The model is an optimization model built around the basic machine repair model. They determine an adequate number of spares and repair channels for replacing and repairing components which randomly fail. Upon failure,
failed components are replaced by spares. A service level constraint is imposed in that there must be adequate spares available at least 90% of the time. It is assumed that there is an infinite input of units into the repair channels. The objective of the model is to minimize expenditures for spares and repair channels subject to the 90% availability constraint. Failure rates and times to repair are considered to be exponentially distributed and an expected MTBF and MTTR are utilized in conjunction with a series queue to determine the number of units in repair.

The cost performance measure utilized in the Gross, Kahn, and Marsh model consists of the following four costs: purchase cost of spares, purchase cost of service channels, repair costs, and investment costs in component reliability improvement programs. No shortage cost is considered since the model does not allow trade-offs between cost and availability. At least 90% availability must be maintained at all times. It is assumed that no shortage costs are associated with the 10% of the time that spares are not available and shortages do occur.

The optimization of the model is complicated, as an integer-nonlinear-programming problem is required. The authors develop a heuristic method instead, that actually considers only the purchase cost of spares and the purchase cost of service channels in the optimization procedure. It
is assumed that the repair costs and the investment costs in component improvement programs are negligible in comparison to the first two costs. Also, the heuristic method considers only one year at a time, allowing the determination of the best maintenance policy on a year to year basis. The model is a single indenture, single echelon model.

Gross and Ince [10] extend the classical machine repair model to allow for the consideration of more than a single stage in the repair phase. A cyclic queueing system is utilized to study the movement of a unit through several phases of repair. An example of a 4 phase system could be removal of a failed machine, transportation to the repair facility, the repair itself, and transportation from the repair facility. Gross and Ince actually assume that stage 1 of the cyclic queue is the machine operating phase. They treat M operating machines as being equal to c1 parallel servers at stage one.

Since a cyclic queue is utilized no assumption of infinite input of units (infinite queue assumption) to the repair cycle is necessary. Also, there is no requirement for a high availability of parts as the Gross, Kahn, and Marsh model called for. Gross and Ince derive exact and heuristic expressions for availability.
The exact expression is:

$$AVAIL_E = A_3 c_1 u_1 \sum_{n_1 = c_1 + 1}^{N} P_E(n_1)$$

where:

$$A_3 = \left[ \sum_{n_1 = 0}^{c_1} n_1 u_1 P_E(n_1) + \sum_{n_1 = c_1 + 1}^{N} c_1 u_1 P_E(n_1) \right]^{-1}$$

and where:

- $c_1 = \text{the number of servers (operators) at stage 1}$
- $u_1 = \text{the steady-state service rate at stage 1}$
- $P_E(n_1) = \text{the steady-state marginal probability that there are } n_1 \text{ customers at stage 1}$

The heuristic expression is:

$$AVAIL_A = \sum_{n_1 = c_1 + 1}^{N} P_A(n_1).$$

where:

$$P_A(n_1) = \text{the approximate model’s steady-state probability that there are } n_1 \text{ at stage 1}$$

In order to obtain the approximate model, Gross and Ince assumed that the first stage, the operating machine stage, is almost always operating at full capacity or, in other words, all $c_1$ machines are up. This is an implication of a high availability constraint such as Gross, Kahn, and Marsh [11] used. The result of this assumption is that the output from the first stage is a pure Poisson process with parameter $c_1 u_1$ and the first stage acts like an infinite source input to the rest of the system.

The decision variables in the Gross and Ince model are: the number of repair channels at each phase of repair.
and the total number of units in the population. The objective of the model is to adjust the decision variables to achieve a desired availability of spares.

2.6 LOGISTICS MODELING, STATE OF THE ART.

Maintenance models such as those discussed in this chapter are used in civilian and military settings. Geisler and Murrie [7] write that the military planner needs maintenance or logistic models to help estimate the cost and effectiveness involved with the use of a particular item or family of items. The logistics model also helps the military planner adopt development and production strategies that will improve the cost-effectiveness of the item being evaluated. The civilian planner is most interested in modeling the characteristics of the market in which an item must operate. The information gained from the model will be used to help reduce operating costs which will in effect increase profits. Although Geisler and Murrie do not mention it, civilian planners involved with the maintenance of production machinery can use maintenance models to gain information on the cost effectiveness of the way in which machinery is procured and utilized and in the way in which the machinery is maintained.

A key point in the above definitions is that logistics models are of great value to personnel involved in planning
functions. Geisler and Murrie go on to write that "Some data suggest that about 80% of the life time logistics costs of an aircraft is determined by decisions made before the aircraft begins to fly. These decisions relate to design tradeoffs of performance against reliability and maintainability, with resulting impact on maintenance manning, initial spare parts procurement, location of repair, and ground support equipment investment." This statement, although specific in referring to aircraft, points out that logistics models can be invaluable as planning tools, thus logistics models must be able to perform trade off and sensitivity analysis to take account of the flexibility and uncertainties existing during planning phases. Frisch [5] reinforces the value of logistics models as planning tools and Fabrycky and Hart [4] emphasize the importance of the trade-off capabilities of a logistics model through their analysis of initial cost and logistics costs tradeoffs. This trade-off is analoguous to the design trade-offs listed by Geisler and Murrie.

Geisler and Murrie point out that logistics models should be able to reflect a weapon system's logistics during peacetime, surge, and sustained combat scenarios. Surge conditions occur when a mobilization begins in response to an act of war. In their article, Geisler and Murrie evaluated logistics models in use in 1981 by the
three major branches of the military. They only evaluated models that could be used to model the logistics requirements of aircraft because the measures of performance applied to aircraft are well defined. The logistics models evaluated were placed in three groups: design models, base-aircraft operations models, and spares allocation models. Following are some of the author's findings regarding logistics models.

Design models are similar to the repair/replace models described in section 2.2 of this chapter in that they evaluate the effects of an item's design characteristics on mission reliability. Base-aircraft operations models are generally large-scale Monte Carlo simulations, in which aircraft are prepared and launched and sorties are flown. These simulated events yield information on the logistics needs of the aircraft and on the performance of the logistics support included in the simulation. The queueing models described in section 2.5 of this chapter provide this type of information, among other things. The spares allocation models evaluated by Geisler and Murrie were generally derivations of the METRIC model described in section 2.3 of this chapter. Geisler and Murrie found that "individually and collectively, their (the models) ability to satisfy all the planning requirements for new weapon systems is limited." Generally, the authors found that
most of the models were designed to evaluate a limited number of maintenance requirements in which it was assumed that necessary data was readily obtainable. Then the models were found to relate their specific maintenance requirement output to logistic performance without considering the interaction of the overall logistics needs of a population. Because of this limitation, surrogate measures of logistics performance have had to be used. For example, the base-aircraft operations models use probabilities of spare parts availability as a surrogate for explicit modeling of inventory structure.

The authors found that most models had been designed to evaluate the logistics requirements of existing weapons systems rather than being designed as a planning tool for new systems. The design models were found to be the most limited in scope. The spares allocation models were not adaptable to nonsteady-state conditions as they assume a steady-state pattern of spare parts demand. The base-aircraft operations models were difficult to adapt to surge and extended warfare conditions and especially to the transient phases leading into and out of those conditions. Furthermore, owing to their Monte Carlo processes, numerical output from simulations is subject to chance variations making the interpretation of their output difficult.
Geisler and Murrie call for the introduction of comprehensive logistics models that can incorporate the required planning capabilities of the three types of models evaluated in their paper. This comprehensive model would have to be analytic to permit optimization and rapid computation to alternative performance measures. The model would have to be dynamic in order to treat nonsteady-state as well as steady-state conditions. Finally, the model should also be able to contend with different levels of detail for a new weapon system so that useful planning could be done with it over the entire range of the life cycle of the system.

A survey of logistics models by Kline [18] echoes some of Geisler and Murrie's conclusions. He states that "It would be desirable to have logistic support models which are useful during all phases of the system life cycle. Unfortunately, most models are useful only beginning with the Full-Scale Development Phase." Kline's paper was a review of logistics models in general that were in use in the military in this country in 1981.

Kline notes that one of the most common assumptions of the logistics models in use is that of steady-state conditions. The models further limit themselves by requiring input data that is not readily available. Another limitation is that the models assume all items to
be in series. Work has been done to eliminate this latter assumption, as is evidenced in an article by Lohmar and Mandel [20] that illustrates the uses of the TIGER computer program developed by the Navy Sea Systems Command. TIGER generates reliability block diagrams which can be used to model a system operating in series, parallel, or series and parallel combined. The model can then be used to provide simulated mean time between failures for the system. Kline notes that reliability block diagram models, such as TIGER, can be used with spares allocation models to overcome the current series limitation.

2.7 SUMMARY.

The literature review has revealed that research applicable to logistics and logistics modeling has been extensive in the last 25 years. Models have been developed to analyze, optimize, or simulate one or more phases of the logistics process utilizing mathematical programming, dynamic programming, and/or computer simulations. Even though logistics tends to be associated with the military, models have been developed with commercial as well as military applications. Many models have gained acceptance in military circles and are in use today, yet research in logistics modeling continues as researchers grope for modeling techniques that provide more accurate answers to real life logistics problems.
The logistics process involves several dependent considerations. The design characteristics of a system being procured must be evaluated with respect to the spares or spare parts inventories and the repair facilities required to meet a specified demand. A complete logistics evaluation includes a determination of the life cycle costs of owning and operating a system of units. Logistics modeling has been further complicated by the lack of sufficient data regarding failure and repair characteristics of systems of units.

Logistics models have tended to focus on one consideration or another, by making simplifying assumptions about the other dependent facets of logistics. One of the major simplifications made has been the assumption that systems operate in steady-state and that logistics requirements may be determined from these steady-state conditions. Logisticians, primarily those involved with military logistics, have begun to call for logistics models that evaluate the complete logistics requirements of a system that does not necessarily operate under steady-state conditions at all times. As stated by Geisler and Murrie [7] "rather than devoting energy to minor improvements in existing models, the model developer should focus on an effort that will produce a big payoff." The "big payoff" will be a new model that logisticians can depend on for
viable solutions to the planning and design of the total logistics system.

This "new" model will have to achieve a balance between simplicity and detailed diagnostic analysis. Just as previously developed logistics models have done, the "new" model will generate a requirement for empirical logistics data, but that empirical requirement must be tempered by certain behavioral assumptions about logistics systems. A model so balanced will possess a generality that will allow application to a broad range of logistics problems, yet retain enough specialization to realistically assist the logistics decision maker with the problems at hand.
CHAPTER III
THE MODELING APPROACH

3.1 INTRODUCTION.

The information presented in this chapter will provide insight into the approach taken in developing the logistics model. The concepts utilized are the key to the model because they allow the evaluation of maintenance requirements for repairable populations during transient as well as steady state phases of operation. Information included in the chapter will describe why these concepts were chosen and how they are applied.

Assumptions made as a part of this model development are detailed as are the parameters and decision variables included in the model. Both the parameters and the decision variables represent data that must be input by the user of the model. Calculations necessary to compute maintenance requirements are detailed using variables that appear in the computerized version of the model. Performance measures used by the model to judge the effectiveness of logistics policy versus maintenance requirements are also described.

The parameters mentioned above indicate variables that the logistics planner generally has no control over and the decision variables represent variables that in many cases
are left to the discretion of the logistics planner. By using the model to play "what if" games with the decision variables, the logistics planner can use the model as an aid to logistics decision making. Changing parameters and evaluating their effect on maintenance requirements may provide information for high level decision makers for their use in establishing parameter values in the future. Besides parameter and decision variable manipulation, other uses of the model are described later in this chapter.

An outline of the limitations created by the modeling approach follows the section on Model Uses. The chapter closes with a summary of the modeling approach.

3.2 TERMINOLOGY.

Certain terms are used frequently in describing the research model. Following are definitions of key terms:

Component - An end item can be broken down into components. The word component refers to subassemblies, parts, or modules of the end item. Each component defined must be assigned a node on the maintenance tree. Note that on the maintenance tree, components at lower levels of indenture are components of components.

End Item - This model is designed to evaluate a population of repairable items. Each item in the repairable population is an end item. The end item occupies Node \(_1\) at the top of the maintenance tree.
Failure Environment - Many times, identically aged end items do not fail at the same rate because of how they are used, where they are used, or because of slight differences in component quality. Therefore, failure environments are created. Identically aged end items within the same failure environment experience the same rate of failure because all of the components that comprise the end item have the same rate of failure. Identically aged end items operating in different failure environments do not experience identical rates of failure for all components.

In Operation - This term applies to end items and is meant to imply that the end items are not in the repair phase, i.e. they are ready for operation or are in use.

Level of Indenture - There are five levels of indenture on the sample maintenance trees in Figures 3.3 and 3.4. The first level of indenture is the end item. The second level of indenture includes major components that make up the end item. (Note that Node 6 represents the probability of fatal failure. It is not a component.) The third level of indenture includes components that are components of the second level of indenture and so forth. The last level of indenture includes spare parts or stockable items required to support the higher levels of indenture. The number of levels of indenture is an indication of the extent to which an end item can be broken.
down into components.

Level of Repair - If there is more than one level of repair then there is more than one type of repair facility available to handle end item failures. The type of failure will determine which repair facility should handle the repair. A level of repair then is a specific type of repair facility.

Node - Each "box" on the maintenance tree is a node. Node_1 represents the end item. Node_6 represents a probability of fatal failure of the end item. Each of the other nodes represents a component of the end item. Data input by the user of the model is used to establish a probability of failure of components represented by bottom of the tree nodes. By moving upward along branches of the tree, probabilities of failure may be determined for each node of the maintenance tree.

Period - The discrete time periods specified by the user of the model, over which all model outputs are calculated. The user directs the model to evaluate maintenance requirements for a certain number of periods. The user can use inventory cycles or any other convenient means for determining the lengths of the periods to be used.

Period Unit - If a period is five days long, the period unit is days. If a period is one month long, the
period unit is months. Period units of days, weeks, months, and years may be used in the present version of the model.

Stockable Item - Any spare part that is required to support the components listed as "bottom of the tree nodes" is a stockable item. By support, it is meant that if the bottom of the tree component experiences a failure, the stockable items represent the spare parts that will be needed to repair that component.

Stream - A stream is a homogeneous group of end items. By homogeneous, it is meant that the end items are identically aged and have identical failure rates for all components.

3.3 MODEL DEVELOPMENT.

The model under development will draw heavily upon some of the concepts utilized by Frisch [5] in his development of a conceptual Markov model. The model will attempt to gain a breadth of coverage found in very few logistics models. By breadth of coverage it is meant that the model will allow the investigation of alternative maintenance policies regarding repair or replace, spare parts inventories, and repair facility characteristics.

3.3.1 Concepts. The model is built upon two major concepts. The first concept is an expansion of the multi-stream idea utilized by Frisch [5] in the development
of a conceptual Markov Model that evaluates the mortality characteristics of populations of spare parts needed to support military weapon systems. The second concept is that of using a maintenance tree to give an organized breakdown of component failure characteristics that govern the maintenance requirements of an end item.

3.3.1.1 Multi-Stream Concept. The model treats the failure of end items as a discrete, nonstationary, Markov process. Generally distributed probabilities of failure are used to determine maintenance requirements at each step of the Markov process. The general distributions used are described in Section 3.3.5. Each step of the Markov Process represents one period. See Section 3.2 for the definition of a period.

A Markov process was chosen because the life cycle of items evaluated by logistics models generally is finite. This finite period may be broken into stages or states in which the item deteriorates toward a final state where one of two things could happen: 1) It is no longer economically or operationally feasible to continue to repair the end item so the end item is retired from operation; or 2) The end item experiences a fatal failure. At each state leading to the final state, there is a probability of a failure and there is the probability that no failure will occur. The no failure/failure possibility
in each state is analogous to a birth-death process. A Markov chain represents a good way to model a birth-death process as long as end items fail randomly. It has already been stated that the failure of end items is governed by generally distributed probabilities of failure, so the random failure requirement is met. Further, the state by state evaluation of the unit life cycle possesses the Markov property, in that it is only necessary to know the present state of an end item in order to forecast future states.

A nonstationary Markov process will be utilized because the model will be used to evaluate nonsteady-state conditions where there is no uniform transition probability from state to state. There may be circumstances under which a population of units never attains steady-state.

In the multi-stream concept employed by this research, a family of nested Markov chains is used to model a population of repairable end items. The population is divided into streams depending upon such parameters as the age of the end item, the number of hours that the end item has operated, or the environment in which the end item operates. Because of the parameter used to divide the end items into streams, each stream represents a homogeneous group of end items. The homogeneity within each group or stream is maintained by applying the same failure
distribution and repair characteristics to each item within a particular stream. In other words, items within a stream are similarly aged, are at the same stage of deterioration, and experience a similar failure environment. Grouping end items into streams avoids the need for item by item tracking.

A stream begins when the first item in that grouping is procured and the stream ends when the last item in that grouping is removed from operation through retirement or fatal failure. Each stream is in effect a Markov chain and all of the streams grouped together or nested together form a model representing the failure characteristics of a population of repairable end items. Each step of the individual streams (Markov chains) represents a period specified by the user of the model. See Figure 3.1 for an illustration of this stream concept.

Even though a discrete Markov process is used to model failure characteristics of end items, a continuous approximation is derived by the model. The accuracy of that approximation is dependent, to a large extent, on the lengths of the periods chosen for evaluation purposes. Each step (period) of the Markov chain representing a particular stream is a discrete approximation of the expected maintenance requirements generated by the end items in that stream. As illustrated by Figure 3.2, when
$t_n$ = time period over which logistician is evaluating inventory requirements (could be on a weekly basis, on an annual basis, etc.)

G-n = age of units. The largest G-n represents the retirement age of the unit.

abc = a stream or a Markov chain (All of the streams together represent the nested Markov chain concept.)

a = number of units procured during time period, $t_n$

$a, b, c \geq 0$

Each node has a maintenance tree attached to it (see Figure 3.3)
Demand for spare part A

Each vertical spike represents the total demand for spare part A during time period $t$. Connecting the tops of the spikes produces a continuous approximation of the demand for A over all time periods. The continuous approximation becomes more accurate as the length of the individual discrete time periods is shortened.

FIGURE 3.2.
CONTINUOUS APPROXIMATION OF MAINTENANCE REQUIREMENTS
these discrete approximations are grouped together, a continuous approximation of the expected maintenance requirements for the end item may be derived. Figure 3.2 uses a period by period spare part requirement as an example.

3.3.1.2 Maintenance Tree Concept. As previously described, for each step (period) of the individual Markov chains (streams), there will be a probability of failure or a probability of no failure for the end items included in that stream. When no failure occurs, no action need be taken by maintenance personnel and the unit continues in operation. When a failure occurs, the affected unit is removed from service and is directed to the appropriate repair facility. A maintenance tree is used to derive the probabilities of these end item failures occurring. The maintenance tree also contains information that governs the repair process (see Figures 3.3 and 3.4).

The maintenance tree allows the end item to be systematically divided into various major components. Below each major component in the maintenance tree will be the family of subcomponents and spare parts that make up the major component. Each level of the maintenance tree represents a level of indenture. At some level of indenture a "bottom of the tree node" will be encountered where it is not practical to break the component
RL  = repair level

MTTR  = mean time to repair

**FIGURE 3.3 MAINTENANCE TREE**
FIGURE 3.4. MAXIMUM MAINTENANCE TREE CONSIDERED BY MODEL
down further. At this node, either failure data is available or can be estimated. Once this level of indenture is reached, a list of stockable parts must be attached to the "bottom of the tree node". This list of stockable parts should include all parts that are intended to be stocked to support the spare parts requirements of that particular bottom of the tree node. The sum of all of the lists of stockable parts should represent a complete list of all the parts that are intended to be stocked to support the spare parts requirements of the end item.

The failure information available for the "bottom of the tree node" is used to establish a failure rate probability distribution for each "bottom of the tree node". Failure information may be derived from data supplied by manufacturers of components, from in house maintenance records, or by extrapolating data from other sources. Once these failure probabilities have been determined and input into the model, they are in turn used to derive the failure probabilities of components at higher levels of the maintenance tree. There is a vertical dependency of failure rates in the tree and a horizontal independence of failure rate at each level of indenture. (See the section on Assumptions, Section 3.3.2, for a discussion of failure rate dependency.) It follows then that conditional probability may be used to compute failure
probabilities at each node of the tree beginning with the given information at "bottom of the tree nodes" and working up to the top of the tree node which represents the end item itself.

As an example of how the probabilities of failure are computed, consider the maintenance tree in Figure 3.5. The lowest level at which a failure distribution is available (in the detailed branch of the tree) is the battery. Component parts listed below the battery are stockable items and do not have failure distributions associated with them. The probabilities of failures of components listed in the tree above the battery are derived by using conditional probability to combine the probabilities of lower levels of indenture, beginning with the level of the battery. As mentioned previously, the failure distribution for the battery node may follow any of several general distributions or specific period by period failure probabilities could be input if they are known. See Figure 3.6 for examples of the general cumulative failure probability distributions that may be used.

Note in Figure 3.4 that Node 6 represents the probability of fatal failure. This is fatal failure of the end item and represents situations in which acts of war, serious accidents, or serious failures cause an end item to be removed from operation permanently. Since this node is
At the component part level, it may be desirable to supply certain information, such as, new cables and clamps are only needed for 10% of the battery replacement. For this example, we are assuming that the last level of indenture possessing a known failure probability distribution is at the battery level. The probabilities of failure of the battery, alternator, and ignition will be combined, using applicable laws of probability, to obtain the $P(\text{fail.})_{ES}$.

\[
P(\text{failure})_{\text{unit}} = P(\text{failure})_{\text{CS}} U P(\text{failure})_{\text{DC}} U P(\text{failure})_{\text{ES}} U P(\text{failure})_{\text{OF}} U P(\text{failure})_{\text{FF}}.
\]

\[
P(\text{no. failure})_{\text{unit}} = 1 - P(\text{failure})_{\text{unit}}
\]

RL = repair level
MTTR = mean time to repair

FIGURE 3.5. MAINTENANCE TREE FOR BATTERY EXAMPLE
connected directly only to the end item node (node_1), only the probability of failure of the end item is dependent on this fatal failure probability. Fatal failure of components is inherently resolved if components that can fail fatally are listed as stockable items at the bottom of the maintenance tree.

The maintenance tree will also be used as a frame to carry other information such as a mean time to repair and a level of repair for each "bottom of the tree node". The mean time to repair (MTTR) and the level of repair (LOR) are input at the same time failure information for each bottom of the tree node is input. See Section 3.3.2.2 for a description of what is included in the MTTR. Several levels of repair will be considered to be available for use upon failure of an item. These levels of repair are analogous to the echelons of repair used by logistics models such as METRIC [31]. LOR is defined in Section 3.2.

3.3.2 Assumptions. This model is intended to introduce concepts that may be employed in evaluating transient state maintenance requirements. With the introduction of these concepts being the main objective of the model several simplifying assumptions have been made. While some of these assumptions may detract from the realistic application aspect of the model, most of these assumptions may be removed by building onto the model.
Sections 4.5 and 6.3 discuss some paths that future researchers may take in expanding this model and making it more suitable for practical application.

3.3.2.1 List of Assumptions. The assumptions utilized may be summarized as follows:

1) Each stream in the nested Markov chains contains a homogeneous group of end items.

2) Minimal repair of end items and certain components is possible, i.e., not all failures are fatal.

3) Minimal repair returns the end item to the state of readiness it was in just prior to failure.

4) The failure of any component represented by a node on the maintenance tree results in an immediate failure of the end item.

5) Failure probabilities are not dynamic unless manipulated manually by the user of the model. For example, if a repair is made on a component part in step n-1 of the Markov chain, the probability of failure of that component part in step n will not be affected by the fact that a repair has occurred.

6) Components at any level of indenture fail independently of the failure of other components at that level of indenture. Only one component can fail at a time.
7) The failure of a component at one level of indentation is dependent on the failure of components at lower levels of indentation that are on a connected branch of the maintenance tree.

8) There is always a chance of fatal failure of an end item. Upon fatal failure, an end item must be removed from service permanently.

9) The user's choice of failure rate distribution will in all likelihood be an assumption on the user's part.

10) Several levels of repair facilities are available.

11) All repair facilities have an infinite capacity.

12) Mean Time to Repair includes the entire amount of time that elapses between failure of the end item/component and the point in time at which the end item is considered in operation.

13) Replenishment of end items through procurement is instantaneous.

14) Purchase costs, procurement costs, repair costs are constant from period to period and are treated as end of period costs in the cost analysis.

15) Repair costs per unit time are the same at all levels of repair. This repair cost includes labor and overhead.
16) The same shortage cost, per unit of time short, is incurred whether the system is one end item short or many end items short. The system is considered inoperable once it becomes one end item short.

17) When a particular "bottom of the tree" component fails, all stockable items listed under that component are required for repair.

18) Demand on end items is constant from period to period.

3.3.2.2 Discussion of Assumptions. Following is a discussion of the assumptions in the order in which they appear above. If the assumption limits realistic application in any way, some comment will be made as to the means for removing the assumption.

Assumption 1) results from the application of the multi-stream concept described in Section 3.2.1.1. This is a timesaving, structural assumption created by the model, not a limiting assumption. End items are grouped into homogeneous streams so that maintenance requirements may be calculated for groups of end items rather than for individual end items.

Assumption 2) simply points out that a repairable population of end items is being dealt with. The end items and many of the components cannot be regarded as throw away
items. This would not qualify as a limiting assumption, but as a descriptive assumption.

Assumption 3) points out that a repair does not return an end item to a "good as new" condition. The respective probabilities of failure of the end items and all components is time dependent, and is not affected by the number or type of repairs that have been performed.

Assumption 4) is a limiting assumption in that it states that the failure of any component listed as a node of the maintenance tree will result in a failure of the end item. This precludes the direct consideration of systems containing noncritical components or redundant (parallel) components. If this model were applied to an end item containing noncritical or redundant components, the availability output given with Assumption 4 would, in effect, be a conservative estimate of the availability for that end item. Creative manipulation of the input data could produce more realistic "out of operation time" data and a more accurate measure of availability.

Assumption 5) can be construed as a limiting assumption, because in many cases a repair can change the failure characteristics of a component or an end item. If the user of this model takes this fact into account when choosing a failure rate distribution and a mean time between failures, then the assumption is no longer
limiting. In other words, it is possible to construct failure data that reflects what the probability of failure becomes after a repair has been made.

Assumption 6) concerns the horizontal independence of failure existing in the maintenance tree. By constructing the tree so that the failure of components at the same level of indenture is independent, the calculation of conditional probabilities of failure in the tree are greatly simplified.

If the failure of one component is dependent on the failure of another component, then Assumption 7) states that if these components could be arranged vertically in the same branch of the tree, then this dependence would be taken into account. The result of Assumption 7) is that the probability of failure of the end item is dependent on the probabilities of failure of all of the "bottom of the tree" nodes plus the fatal failure node 6.

Assumption 8) could be considered a realistic assumption in that it states that the probability of a fatal failure of the end item must be taken into account. This fatal failure aspect can be very useful in any situation where, for some reason, end items must be permanently removed from operation on a frequent basis.

Assumption 9) emphasizes that the user of the model will in all likelihood make assumptions in determining the
failure rate input data. Assumptions about mean time between failures and the distribution of failure rates about that mean must be made in order to obtain the expected failure rates which, in turn, are used by the model to perform maintenance requirements planning. The section on Data Requirements (Section 4.2) will comment further on the number of assumptions that must be made when organizing failure data of any kind.

Assumption 10) points out that there may be cases where there is more than one level of repair available to perform repairs. Since this model is designed to function in a military logistics setting, the U.S. Navy LOR system would serve as a good example of levels of repair available. The first level of repair in this system is the organizational level which represents repairs that are made, for instance, aboard a ship. For various reasons, certain repairs may not be made aboard ship, but are sent to a second level of repair, the intermediate LOR, which may be located at the ship's home port. The third level of repair handles repairs that cannot be made at the first two levels and is called depot repair. This type of facility represents an even more centralized repair facility that may serve a large geographical area.

Assumption 11) states that there is infinite capacity in the repair facilities. This assumption of infinite
capacity was made in an effort to allow the use of expected MTTR's and to avoid simulating repair channel operations. A major extension of this model would be to model repair channel operations more exactly. This would probably entail the use of an event driven simulation model.

Assumption 12) states that the entire amount of time that a unit is out of operation due to a failure is included in the expected MTTR's. This means that time spent diagnosing the failure, travel time to the repair facility, queue time at the repair facility, time spent waiting on parts, the actual repair time, and transportation time back to the theater of operation is all included in the one MTTR term that is input by the user of the model. This assumption allows the user of the model to take into account the queueing time assumed away by assumption 11. The assumption does require that quite a bit of data be collected regarding the repair process before the user can state an appropriate MTTR.

Assumption 13) is strictly a simplifying assumption that does depart from realism in many cases. Certain end items can require a significant amount of lead time before they can be obtained and placed into operation. This assumption can be circumvented through the proper interpretation of the output results. Since this model is used for planning purposes, the output concerning end items
needed should be interpreted strictly as end items needed and at what time period they are needed. If the user of the output data is familiar with lead times involved in procuring end items, it would be an easy matter to calculate the points in time at which end item procurements should be initiated. The only model output that would change as a result of this adjustment is that procurement costs for end items would be incurred in earlier periods.

Assumption 14) also is a simplifying assumption that can depart significantly from realism in certain cases. Additional scenario generators that operate much the same as the model subroutines that compute procurement amounts, could be appended to the model to simulate cost increases or inflation. The length of period chosen by the user of the model will determine whether or not the treatment of cost as occurring at the end of the period will have a significant effect on the evaluation of logistics policy costs.

Assumption 15) is a limiting assumption in cases where there are different levels of repair that typically have significantly different overhead rates or labor rates from level to level. Additional model subroutines could also overcome this assumption.

Assumption 16) is a limiting assumption because it does not allow the model to evaluate systems of end items
that can continue to operate even when one or more end items short of the number of end items required to meet the demand. Information regarding the number of end items short could be easily derived from output presently calculated by the model. A shortage cost that is sensitive to the number of end items short could be incorporated into the model so that the effects on cost of being a specific number of end items short can be evaluated.

Assumption 17) limits the model's ability to give accurate spare parts inventory requirements for components that do not require the same spare parts at every failure. Again, subroutines to accommodate these situations could be built into the framework of the existing model.

The last assumption, Assumption 18) is a simplifying assumption that again could be overcome by adding a scenario generator that would operate in a manner similar to the model subroutines that compute procurement amounts. The demand being referred to here is the number of end items that must be operating in each failure environment in order to complete their respective missions. Demand is further described in Section 3.3.3 on Parameters.

3.3.3 Parameters. The model requires the input of certain information that generally will not be under the control of the logistics decision maker. It is the task of the user of this model to input these fixed parameters and
then develop the best logistics policy possible given these specific circumstances. Following is a description of the input parameters considered by the model:

Interest Rate - An interest rate must be input so that the time value of money may be considered when calculating logistics policy costs.

End Item Costs - The first cost of end items, the book values of used end items, and the salvage cost of a retired end item all are controlled by market conditions beyond the control of the logistics decision maker. If the decision maker has a selection of end items from which to procure, then the decision maker can have some effect on the end item dollar values that are actually input into the model. For this reason, end item costs are also included under the decision variable of quality which is described in the next section. Another end item cost is the administrative cost of procurement which is a cost probably not under the control of the logistics decision maker.

Spare Parts Costs and Spare Parts Lead Time - The market, not the logistics decision maker will control the price of spare parts and also the lead time involved with procuring spare parts. The decision maker can have some impact on spare parts costs through the brand name part that is selected. This impact is described further under the decision variable of quality in the next section. The
procurement and warehousing costs associated with spare parts is also assumed not to be under the control of the logistics decision maker.

Failure Characteristics of End Items and Components - A brand-dependent mean time between failure and mean time to repair is typical to the brand name end item or spare part procured. The logistics decision maker has no direct control over these characteristics. It is conceivable that preventive maintenance policies could affect the MTBF or even the brand-dependent MTTR. The model has no direct ability to calculate this effect, so if preventive maintenance programs are in place, the effect on MTBF and MTTR must be allowed for before this information is input into the model. Brand-dependent MTBF and MTTR characteristics are the characteristics that are affected by the quality of the end item or spare part being procured.

Demand - Within each failure environment there will be a specified number of end items required in order for a particular mission or service to be performed. Demand establishes a framework within which the decision maker must form his logistics policy. The logisticians's success in meeting the demand is measured by the availability of the system(s) of end items.
Availability - A level of availability desired or required is generally established by someone other than a logistics decision maker. The availability and the demand parameters are interrelated.

Repair Costs - Costs associated with the repair of an end item must include labor and overhead associated with diagnosis of the cause of failure, transportation to the repair facility, the actual repair, and transportation back to the site of operation. More specifically, the overhead cost should include cost of operating transportation equipment and the cost of operating the repair facility. Capital costs involved with establishing repair facilities should not be included. If the logistician's purpose in using the model is to obtain accurate cost data, a great deal of data must be collected in order to arrive at an accurate repair cost per period.

Shortage Costs - When the demand is not met, there is a certain penalty incurred. In order to gauge the effects of shortages, a dollar value is assigned to this penalty. Shortage penalties may include lost revenue, lost time, damaged machinery, personnel injury, or loss of life. The decision maker must control the decision variables available to him in order to meet specified levels of availability and keep shortage penalties to a minimum.
3.3.4 Decision Variables. Since logistics models are important planning tools, a great deal of flexibility must be built into the models so that many variables and many alternatives may be considered. Of the variables that must be input into the model, many will be under the control of the decision makers using the model. By playing "what if" games with the model, the effects of various combinations of decision variables on the cost of logistics policy and availability of end items may be evaluated.

Following is a description of the decision variables considered by the model:

Length of Period - In the development of this model it was assumed that in most cases it would be desirable to know the maintenance requirements of end items over consecutive time periods of a particular length. For example, if inventory policy requires reporting spare parts quantities once a month then it would be logical to choose a month time period and let the model not only compute spare parts requirements on a month by month basis, but give repair manpower requirements, failure probabilities, end item availability, and logistics policy costs on the same monthly basis.

Quality - A family of variables including first costs of end items and spare parts, failure characteristics of end items and components (MTBF), repair characteristics of
end items and components (MTTR), and depreciated values of end items all combine to help determine the relative quality of end items and components that are chosen for use. Assuming that there is more than one manufacturer of the end items and components that must be procured, there should be variations in quality and price, and therefore choices to be made by those responsible for procurement. Frisch [5] utilizes quality as a decision variable in his mortality model and discusses the implications of quality decisions.

Procurement Policy - This is another decision variable discussed in depth by Frisch [5]. The method by which end items are procured and therefore the way in which a population of end items is built can have a significant impact on the availability of end items, the cost of logistics policy, spare parts requirements, and repair facility requirements. This model allows the user to be very flexible in selecting procurement policy. The following alternatives are available:

1) Build the population all at one time through one block procurement.
2) Build the population through uniform procurement amounts occurring at equal time intervals.
3) Build the population through decreasing procurement amounts occurring at equal time intervals.
4) Build the population through increasing procurement amounts occurring at equal time intervals.
5) Build the population strictly at the discretion of the user by procuring designated amounts at specified points in time.
Further variations possible include: building the population of end items infinitely, building to an upper population limit, or replacing end items only upon fatal failure in order to maintain a specified population size.

Size of the End Item Population - This decision variable is intertwined with several of the other decision variables. For example, if the size of the end item population is varied, some other variable will probably have to change if there is an availability requirement to be met. The decision maker can choose to have a smaller population, but this will probably mean that better quality end items that fail less frequently and are easier to repair must be utilized. Or it may be possible to survive with a smaller population if the MTTR per end item can be reduced significantly by implementing changes at the repair facilities.

Retirement Age - A very important decision generally at the discretion of the logistician is, when should end items be retired from service? Setting the retirement age of end items must be based on several different factors. A point may be reached where it is no longer economical to continue to repair an end item. The economics are affected by the required availability of the population of end items, the cost of parts, the cost involved with repair, and the first cost of end items. A second factor that must
be considered is the fact that populations of end items become obsolete. If there is the option to gracefully retire end items over a period of time, varying the retirement age variable could offer some insight on the cost involved with some type of phase out policy.

Mean Time to Repair - Since the MTTR in this model includes such a wide range of events, there would be many opportunities for the decision maker to decide to make certain changes in repair policies that would affect availability of the end items, spare parts requirements, repair facility manpower requirements, and logistics policy costs. Any changes made in repair policies would have to be documented separately by the user of this model as the model only tracks the final MTTR value for components in the maintenance tree.

Inventory Policies for Spare Parts - The logistician will probably have some control over lot sizing techniques used for spare parts. For large populations of end items, the amount of spare parts stocked can carry a significant cost as far as inventory costs are concerned or a significant penalty if down time of end items is increased because of part shortages.

It is recognized that in most situations certain of the above variables are fixed and may not be changed by the decision maker. It is, however, the job of the decision
maker to formulate the best logistics policy under the given circumstances. Varying the decision variables available to the logistically and weighing the effects of changes in these variables on availability, logistics policy cost, repair manpower requirements, and spare parts requirements will help the logistician to approach the most effective and efficient logistics policy possible.

3.3.5 Calculations. As would be expected, many calculations and approximations are used by the model to produce maintenance requirements. This section will detail the calculations used. The variable names and symbols used here will not necessarily match the variable names used in the computerized version of the model.

3.3.5.1 Probability of Failure. A probability of failure for each period must be calculated for the component represented by each "bottom of the tree node". A probability of failure for each period also must be calculated. These probabilities of failure either may be input directly by the user of the model or may be generated by the model. If the model is to generate these probabilities, one of the general failure distributions, identified by the user as appropriate to a specific component, will be used. The user programs the model by selecting a failure distribution and inputting an MTBF for each component. There are five choices of failure
distributions that may be used to compute failure probabilities.

Following is a description of the equations used by each of the five failure distributions to compute the probability of failure for the component represented by each "bottom of the tree node". The user of the model also assigns a failure distribution to the fatal failure node, NODE_6. See Figure 3.6 for a graphical representation of the failure distributions employed.

List of Variables:

1/\lambda = Mean Time Between Failures for the component represented by the "bottom of the tree" node. This value is input by the user of model. \lambda is the failure rate of the component.

e = irrational number = 2.718282.

t = # of periods that the end item, of which the component is a part, has been in operation.

F_X(t) = cumulative probability of a failure of the component at some point in time t.

\text{NODE}_i = probability that a failure of the component will occur during the given time period.

i = "bottom of the tree" node number as identified by position in maintenance tree.

\pi = irrational number = 3.141593
FIGURE 3.6. CUMULATIVE FAILURE PROBABILITY DISTRIBUTIONS

graph a. Uniform

graph b. Increasing Exponential

graph c. Exponential

graph d. Approximate Normal

graph e. Bathtub
List of Equations:

Uniform Distribution:

\[ F_X(t) = \frac{\lambda t}{2} \]

Exponential Distribution:

\[ F_X(t) = 1 - \frac{1}{e^{\lambda t}} \]

Increasing Exponential Distribution:

\[ F_X(t) = \frac{1}{e^{1/\lambda}} * e^{t/2} \]

Approximate Normal Distribution:
(Weibull with shape parameter = 3)

\[ F_X(t) = 1 - \frac{1}{(\lambda t)^3} \]

Bathtub Distribution:

\[ F_X(t) = \frac{1}{e^2} * e^{\lambda t} \]

In the Uniform, Exponential Increase, and Bathtub distributions, the coefficients have been chosen such that when an end item has been in operation for a period of time equalling twice the MTBF of the respective function, the probability of a failure of the component represented
becomes 1.0. The Exponential distribution is a tangential function that approaches a failure probability of 1.0 as time approaches infinity. The approximate normal shape is produced by using a Weibull distribution with a shape parameter of 3. This produces a probability density function that is shaped similarly to the Normal but skewed slightly to the right. The cumulative distribution function is tangential and approaches 1.0 as time approaches infinity.

Even though the Exponential and Weibull cumulative probability functions theoretically never attain the probability of 1.0, it is assumed in the model that the probability of failure = 1.0 for a given component at the end of that component's expected life span. A component's expected life span is assumed to be equal to twice the MTBF for the component. After the end item has been in operation a period equal to twice the component's MTBF, the probability distribution for this component regenerates. Figure 3.7 illustrates this concept.

The Uniform distribution would be suitable to use in situations where the component being evaluated has a constant probability of failure from period to period. The Exponential distribution is suitable in
MTBF<sub>c</sub> = .75t = .75 months

MTBF<sub>c</sub> is the mean time between failures for component c.

t = 0 is the point in time at which the end item, of which component c is a part, first went into operation.

The cumulative failure probability distribution for component c regenerates after reaching an upper limit of 2*MTBF<sub>c</sub>.

FIGURE 3.7.

UPPER LIMIT OF CUMULATIVE FAILURE PROBABILITY DISTRIBUTIONS
situations where the probability of failure decreases exponentially with time. The increasing exponential distribution represents the opposite scenario where the probability of failure increases exponentially with time.

The last two curves also represent opposite situations. The approximate normal distribution would apply where failure rates are low in the early and late stages of the life of a component. The bathtub distribution applies in situations where there are higher failure rates during the burn-in period of a new component, lower rates of failure during the majority of the life of the component and then higher rates again during the later stages of component life.

The user of the model will be able to obtain inventory requirements based on a time period of his choice. This may require that given failure rate information be adjusted to meet the chosen time scale. As an example, consider a car battery that has the cumulative failure probability distribution shown in graph c of Figure 3.6. The battery is a part of the maintenance tree for an automobile. The battery's position in the automobile maintenance tree is shown in Figure 3.5. Note that information regarding mean time to repair and level of repair for battery replacement are noted in that figure. A large fleet of automobiles is being operated and the logistician must know how many
batteries to stock on a weekly basis. Graph c is an Exponential probability distribution, so the following calculations may be used to find the mean time between failure for each battery assuming that \( F_X(4) = 0.6 \).

\[
F_X(t) = 1 - e^{-\lambda t}
\]

\[
0.6 = 1 - e^{-4\lambda}
\]

\[
\frac{1}{\lambda} = MTBF = 4.365 \text{ years}
\]

To find the probability of failure of a battery during week one, the following calculation would be used:

\[
p(f)_1 = 1 - e^{-(1/52)/4.365} = 0.004
\]

To find the probability of failure of a battery during the first two weeks, the following calculation would be used:

\[
p(f)_{1,2} = 1 - e^{-(2/52)/4.365} = 0.009
\]

The probability of failure of a battery during week two alone is:

\[
p(f)_{1,2} - p(f)_1 = .009 - .004 = .005
\]

The probability of failure of a battery during subsequent weeks would be calculated using this logic.

3.3.5.2 Probability of Failure of End Items. The probability of failure of the end item is conditional on the probability of failure of all of the "bottom of the tree" nodes plus the fatal failure node, NODE_6. The probability of failure for nodes located at intermediate levels of the tree (between the "bottom of the tree nodes" and the end item node) are conditional on the probability
of failure of nodes connected directly beneath them. Steps required to compute NODE\(_i\) (probability of failure of end item) are:

Step 1: Compute NODE\(_i\) of the bottom of the tree nodes as described in previous section.

Step 2: Use conditional probabilities, assuming horizontal independence of failure in the maintenance tree, and work towards the top of the tree. The formula listed below would be used to calculate NODE\(_i\) once the conditional probability calculations have proceeded to that level of indenture in the tree. See the Venn Diagrams in Figure 3.8 for a graphical explanation of the formula.

\[
\text{NODE}_1 = \text{NODE}_2 + \text{NODE}_3 + \text{NODE}_4 + \text{NODE}_5 + \text{NODE}_6 \\
- \prod_{i,j=2,\ldots,6} \text{NODE}_i \cdot \text{NODE}_j \\
+ \prod_{i,j,k=2,\ldots,6} \text{NODE}_i \cdot \text{NODE}_j \cdot \text{NODE}_k \\
- \prod_{i,j,k,m=2,\ldots,6} \text{NODE}_i \cdot \text{NODE}_j \cdot \text{NODE}_k \cdot \text{NODE}_m \\
+ \prod_{i,j,k=2,\ldots,6} \text{NODE}_2 \cdot \text{NODE}_3 \cdot \text{NODE}_4 \cdot \text{NODE}_5 \cdot \text{NODE}_6
\]
Each ellipse represents the probability of failure of a separate component. When the components are assembled together they form an end item. Since components fail independently, the following combinations of component probabilities must be evaluated and combined in order to determine the probability of an end item failure.

$$f_1(t) \cup f_2(t) \cup f_3(t) \cup f_4(t) \cup f_5(t) =$$

![Diagram of Venn diagram with combinations and unions of ellipses]

FIGURE 3.8. COMPUTATION OF CONDITIONAL PROBABILITIES
3.3.5.3 End Item MTTR. The mean time to repair end items must be known in order to compute availability and repair facility manpower requirements. This value is computed using the MTTR values entered for the individual components represented by "bottom of the tree" nodes. Following are the variables and equations used to compute end item MTTR:

List of Variables:

- \( MTTR_i \): MTTR if the component represented by node \( i \) fails. \( MTTR = \frac{1}{u} \) where \( u \) = the rate of repair. (MTTR is input by the user of model.)
- \( NODE_i \): probability of failure in a given time period of the component represented by the bottom of the tree node \( i \).
- \( MTTRSUM_s \): weighted sum of MTTR's for one end item in a given stream \( s \).
- \( MTTRAVG_s \): average amount of time spent in repair during a given period by an end item in stream \( s \). End items in different streams may have different \( MTTRAVG_s \).
- \( B \): total number of "bottom of the tree" nodes

Equations:

\[
MTTRSUM_s = \sum_i [MTTR_i \times NODE_i]
\]

\[
MTTRAVG_s = \frac{MTTRSUM_s}{B}
\]
3.3.5.4 Availability. Now that the probability of a failure of the end item and the amount of time that an end item spends in repair have been calculated, all of the data is in place for the availability calculations. Following are the variables and equations used to compute end item availability.

List of Variables:

- \( N_s' \) = \# end items in operation in stream \( s \) at the beginning of time period, \( s = 1, \ldots, \) total \# streams.
- \( N_s'' \) = \# end items in operation in stream \( s \) at end of time period.
- \( N_s \) = average \# end items in operation in stream \( s \) during time period.
- \( N_e \) = total \# end items in operation in environment \( e \) during time period, \( e = 1, \ldots, \) total \# environments.
- \( R_e \) = total amount of time spent in repair by end items in environment \( e \).
- \( \text{MTTR}_e \) = MTTR per end item in environment \( e \).
- \( \text{NODE}_{1s} \) = probability of failure of an end item in stream \( s \). The probability of fatal failure is not considered. The effect of fatal failure on availability is taken into account when determining the average number of end items in operation in a stream during a given time period.
- \( \text{SUM}_{(f)}_e \) = weighted sum of the chance of failure of end items in environment \( e \).
- \( P(f)_e \) = average chance of failure of an end item in environment \( e \).
\( P(f)_e' \) = average chance of failure of an end item in environment \( e \) during a period of time equal to MTTR\(_e\).

LTP = length of a time period (input by user).

The equations are as follows:

\[
N_s = \frac{[N_s' + N_s'']}{2}
\]

\[
N_e = \sum_{s \in e} N_s
\]

\[
R_e = \sum_{s \in e} [N_s \times MTTRAVG_s]
\]

\[
MTTR_e = \frac{R_e}{N_e}
\]

\[
SUM(f)_e = \sum_{s \in e} [N_s \times NODE_1s]
\]

\[
P(f)_e = \frac{SUM(f)_e}{N_e}
\]

\[
P(f)_e' = \frac{MTTR_e}{LTP} \times P(f)_e
\]

In order to calculate the availability of end items, some means must be derived for calculating the probability of being short one or more units. The availability will be:

\[
A_e = 1 - \sum_{x=1}^{D_e} M_x
\]

\( D_e \) = the demand in environment \( e \).
$M_x = \text{the probability of } x \text{ end items out of operation.}$

Another way to write this would be:

$$A_e = \sum_{x=0}^{k} M_x \quad \text{where } k = N_e - D_e$$

It is assumed that when the number of end items in operation in a given environment becomes less than the demand for end items in that environment, then at that point in time, the availability of that system of end items is 0. The availability calculations determine the probability that, for a given time period, the number of units in operation is greater than or equal to the demand. This probability represents the availability of end items versus the demand. If the number of end items out of operation at any given time remains between 0 and $k$ for an entire time period, then the availability for that time period would be 100%.

The chance of failure of any one end item is independent from the chance of failure of any other end item within or outside of the same stream. Further, because of the homogeneity of the streams, all end items within a stream have the same probability of failure. In the above calculations the value $P(f)_e$ establishes an average probability of failure for all end items operating in the same failure environment, so all end items operating
in the same failure environment in effect have an equal probability of failure. There are two things that can happen to an end item during a given period: either the end item experiences a failure, or the end item experiences no failure.

With the characteristics of the foregoing paragraph in mind, it can be assumed that the probabilities of $0, 1, 2, \ldots, N_e$ simultaneous failures of end items is binomially distributed. The binomial distribution as applied to a population of end items would be defined as follows:

$$ \sum_{x=0}^{n} b(x; n, p) = 1 $$

$n = \text{total number of end items in the population.}$
$p = \text{probability of failure of an end item.}$

To calculate availability, we only need to know the probability of 0 to $k$ end items being out of operation simultaneously. Thus the binomial calculation for availability becomes:

$$ A_e = \sum_{x=0}^{k} b(x; n, p) $$
\[ A = \sum_{e} \left[ \left( A_e \times N_e \right) / N \right] \]

\[ A_e = \text{the availability of end items operating in environment } e. \]

\[ k = N_e - D_e \]

\[ D_e = \text{the demand for end items operating in environment } e. \]

\[ p = P(f)_e' \]

\[ A = \text{availability of the entire population of end items.} \]

\[ N = \text{total # of end items in operation during a given period.} \]

The \( P(f)_e' \) term needs some explanation. Referring to Figure 3.9 it can be seen that the average MTTR (MTTR\(_e\)) is not necessarily equal to the length of a time period (LTP). In order to find availability, it is necessary to evaluate the probability of simultaneously having more than \( k \) units out of operation. By evaluating a time period of length MTTR\(_e\), the probability of multiple failures occurring at the same time can be approximated. In order to calculate \( P(f)_e' \), it must be assumed that the probability of failure is linear across any given time period (LTP).

Graph a. of Figure 3.10 illustrates the method used to calculate availability when at some point during a time period, the total number of end items operating in an environment becomes less than the demand of end items in
MTTR\textsubscript{e} = the average MTTR for an end item operating in a particular failure environment.

LTP = length of one period

LMR = length of model run

If the probability of failure of end items was evaluated over one entire period, LTP, the evaluation of simultaneous failures of end items would be difficult. Difficulty occurs because there is a probability that events such as the following could occur. If MTTR = 1/6 * LTP then it is possible that 6 end item failures could occur during the time period, LTP, without an overlap of "out of operation time".

If the evaluation period is shortened to MTTR\textsubscript{e}, the model assumes that if more than one end item failure occurs during the period, MTTR\textsubscript{e}, then simultaneous failure has occurred. The availability subroutine evaluates the probability of 0 to k failures occurring within a time period of length MTTR\textsubscript{e}.

FIGURE 3.9. EXPLANATION OF P(f)\textsubscript{e}
Graph a. $N_s' > D_e$ and $N_s'' < D_e$

\[ a = N_s' - D_e \quad b = D_e - N_s'' \quad x = \frac{(a/b)}{(a/b + 1)} \times \text{LTP} \]

$LTP = $ one time period $\quad A = \text{Availability for LTP}$

$A_x = \text{Availability for } x \quad A_y = \text{Availability for } y$

$A_x$ is calculated as outlined in Section 3.3.5.4.

$A_y = 0$ then $A = \frac{x}{x+y} \times A_x$

Graph b. $N_s' = D_e$ and $N_s'' < D_e$

\[ b = D_e - N_s'' \quad x = \frac{1}{b + 1} \times \text{LTP} \]

$A_x = \sum_{x=0}^{0} b(x; n, p) \times \frac{x}{x+y} : n = N_e, \quad p = P(f)_e'$

$A_y = 0$ then $A = A_x$

FIGURE 3.10. AVAILABILITY WHEN $N_s'' < D_e$
that environment. Total number of end items operating includes the end items actually in operation plus end items in repair. During the course of a time period, fatal failure is the only cause of the reduction in total number of end items.

If at the start of a period, the number of end items in an environment is less than the demand for that environment, the availability for that period is 0. This must be the case since it was assumed that the number of end items in operation must meet the demand for that particular system of end items in order for that system to be operable. If at the start of a period, the number of end items in an environment is equal to the demand for end items in that environment, it is assumed that the fatal failure(s) of end items occurring within the period occur at equal intervals. Then, the time to first failure is calculated as shown on graph b. in Figure 3.10.

3.3.5.5 Procurement Amounts. As described previously, the user of the model may select one of five different procurement policies to follow when procuring end items. Besides the option of procuring based on the period by period inputs of the user, the model could be programmed to procure in uniform amounts, block amounts, increasing amounts, or decreasing amounts. The model must perform calculations of the amount to procure if an increasing or
decreasing amount policy is selected. The user inputs a percentage increase or decrease and the model computes the procurement amount simply as:

\[
\begin{align*}
\text{increase:} & \\
P_p &= P_{p-1} + \left[ P_{p-1} \times \frac{g}{100} \right] \\
\text{decrease:} & \\
P_p &= P_{p-1} - \left[ P_{p-1} \times \frac{g}{100} \right]
\end{align*}
\]

- \( P_p \) = amount to be procured on the \( p \)th procurement.
- \( P_{p-1} \) = amount procured on the \( p-1 \) procurement.
- \( g \) = percentage increase or decrease in procurement amount input by user.

Under the uniform procurement options, \( P_p \) is defined by the user at the beginning of the program and remains constant except as noted below. Under the block procurement policy there is of course only an initial block procurement amount defined by the user. In the four programmable procurement policies, the user may specify that an upper limit on the number of end items in the population be maintained. In this case, the model checks the difference between the upper limit and the number of
units in operation at the end of the period and compares this to $P_p$ before determining the actual amount to procure:

$$\text{difference} = \text{UPLIMIT} - [N - (N \times NODE_6)]$$

UPLIMIT = upper population limit input by user.
N = total number of end items in operation.
NODE_6 = probability of failure occurring within the given period.

If the difference is greater than $P_p$, then the amount procured is $P_p$. If $P_p$ is greater than the difference, then the difference is the amount actually procured and $P_p$ is set equal to the difference. The amount procured is rounded to the nearest integer value.

3.3.5.6 Spare Parts Requirements. Totals of each type of spare part required to support the population of end items are calculated for each bottom of the tree component. This information is provided for each stream and for the population in total at the end of each period. From these values, the period warehouse space requirements at each level of repair are derived.

$$Q_j = NODE_{i} \times n \times N_s$$

$$W_j = Q_j \times w_j$$
NODE\text{\textsubscript{i}} = \text{the probability of failure for the given time period of the component represented by "bottom of the tree" node i.}

n = \text{the total number of spare part j required to support the "bottom of the tree" node component to which it is attached.}

N_s = \text{the average number of end items in operation in stream s during the given time period.}

Q_j = \text{the total number of spare part j needed to support stream s during the given period.}

w_j = \text{the total amount of warehouse space in cubic feet taken up by one of the spare parts j.}

W_j = \text{the total warehouse space in cubic feet required to store Q_j of part j.}

The sum of the Q_j required for each stream gives the number of spare part j needed to support the total population for one time period. Summing the W_j of all spare parts by repair level gives an indication of the total warehouse space that must be reserved for parts at each LOR.
If the user of the model instructs the model to calculate inventory levels and generate order policies and costs based on EOQ, the following calculations are performed:

\[ Q_j' = \sqrt{\frac{2 \times PC_j \times Q_j}{HC_j}} \]

\[ L_j' = Q_j \times LT_j \]

\[ DAYS_j = \frac{Q_j}{Q_j'} \]

\[ TC_j' = \frac{(C_j \times Q_j) + \sqrt{(2 \times PC_j \times HC_j \times Q_j)}}{} \]

- \( Q_j \) = total number of spare part \( j \) needed to support a given stream of end items during a given period.
- \( PC_j \) = procurement cost incurred every time a procurement of spare part \( j \) is initiated.
- \( HC_j \) = the cost to warehouse one unit of spare part \( j \) for one period. This includes the cost of space occupied, warehouse facility labor and overhead costs, and cost of equipment supporting warehouse.
- \( Q_j' \) = the economic order quantity for spare part \( j \).
- \( LT_j \) = the lead time in days for spare part \( j \).
- \( L_j' \) = the economic order level for part \( j \).
- \( DAYS_j \) = the number of days between orders of spare part \( j \).
- \( C_j \) = the price of one unit of spare part \( j \).
\( TC_j' \) = the cost of the EOQ policy for the total number of spare parts \( j \) required to support the given stream of end items for the given period.

### 3.3.5.7 Cost of Logistics Policy

The cost of logistics policy is calculated per stream per period and then totalled for the period. At the end of the model run a final total cost of logistics policy for the time periods covered by that model run is given. The period costs are converted to present worth values, utilizing equations detailed below. After the model has evaluated the last time period, all present values are summed and converted to a period equivalent cost. This period equivalent cost (average logistics policy cost per period) should provide a figure that can be easily compared against different logistics policy period equivalent costs computed on other runs of the model.

The factors for converting to present value and to annual equivalent values, as taken from Thuesen, Fabrycky, and Thuesen [34] are as follows:

\[
P = F(P/F \ i, n) = F \times \frac{1}{(1+i)^n}
\]

\[
A = P(A/P \ i, n) = P \times \frac{i \times (1+i)^n}{(i+i)^n - 1}
\]
P = present worth value
A = annual equivalent cost
F = future value
i = time value of money (for example, the current interest rate)
n = time periods

The costs considered in developing the logistics policy cost are:

Capital Cost - The first cost of an end item, the book value received for a failed end item, and the salvage value received for a retired end item are factors considered in calculating the capital cost. Capital cost is computed on a per period basis using the following equation:

\[ CC_e = (P_{pe} \times CC') - (NF_e \times SV') - (NR_e \times BV_e') \]

- \( CC_e \) = capital cost for end items in environment e.
- \( P_{pe} \) = number of end items procured and placed in environment e.
- \( CC' \) = first cost of an end item.
- \( NF_e \) = number of end items failing fatally during period.
- \( SV' \) = salvage value for a failed end item.
- \( NR_e \) = number of end items retired at end of period.
- \( BV_e \) = book value for retired end item from environment e.
Repair Cost - The repair cost per period unit (see Section 3.2 for a definition of period unit) times the total amount of time that units spend out of service gives the repair cost. Repair cost per period is calculated using the following equation:

\[ RC_e = RC' \times R_e \]

- \( RC_e \) = repair cost per period for end items in environment \( e \).
- \( RC' \) = repair cost per period unit. See section 3.2 for definition of period unit.
- \( R_e \) = total amount of time spent in repair by end items in environment \( e \).

Shortage Cost - The shortage cost per period unit times the amount of time the demand is not met gives shortage cost. Shortage cost per period is calculated using the following equation:

\[ SC_e = (1 - A_e) \times SC' \times LTP \]

- \( SC_e \) = shortage cost per period for end items in environment \( e \).
- \( A_e \) = availability of end items in environment \( e \).
- \( SC' \) = shortage cost per period unit.
- \( LTP \) = number of period units in one period, i.e. length of time period.

Inventory Cost - The sum of the \( TC_j \)' described in the previous section constitute the inventory cost. The
following equation is used to calculate inventory cost:

\[ IC_e = \sum_{j} TC_{je} ' \]

\( IC_e \) = total inventory cost per period for end items in environment e.

\( TC_{je} ' \) = inventory costs for spare part j which is a stockable item for an end item in environment e.

Procurement Cost - The administrative cost incurred when end items are procured constitutes procurement cost. This cost is a total period cost and is not allocated as an environment cost. The following equation is utilized:

If \( Pt > 0 \)

\[ PC_t = 1 \ast PC' \]

\[ PPC_t = PC_t \ast (P/F i,n) \]

\( Pt \) = number of end items procured at beginning of period t.

\( PC_t \) = procurement cost for period t.

\( PC' \) = procurement cost per procurement.

\( PPC_t \) = present worth of procurement costs in period t.

\((P/F i,n)\) = factor to convert from end of period cost to present worth value.

\( i \) = interest rate adjusted to period length.

\( n \) = t (number of time periods)

Total Cost - The model produces a total period cost for each environment. These figures are converted to
present worth values and summed. The sum of period present
worth values is then converted to a period equivalent cost.
and total model run costs for each environment and for the
entire population of end items are calculated. The
following equations are used:

\[
TC_{te} = CC_e + RC_e + SC_e + IC_e
\]

\[
PTC_{te} = TC_{te} (P/F i,n)
\]

\[
ATC_e = \left[ \sum_{t=1}^{\text{LTP}} PTC_{te} \right] (A/P i,n)
\]

\[
TC = \sum_e ATC_e + \left[ \sum_{t=1}^{\text{LTP}} PPC_t \right] (A/P i,n)
\]

- **TC<sub>te</sub>** = total cost of logistics policy for environment <i>e</i> in period <i>t</i>. Procurement costs of end items are not included.
- **TC** = population total cost of logistics policy.
- **PTC<sub>te</sub>** = present worth value of period total costs.
- **ATC<sub>e</sub>** = period equivalent cost of logistics policy for environment <i>e</i>.
- **(A/P i,n)** = factor to convert from present worth to period equivalent cost.
- **i** = interest rate adjusted to period length.
- **n** = LTP

3.3.6 Measures of Performance. Two primary measures of performance are utilized. First, when given the appropriate data, the model returns the costs associated with the input logistics strategy. The previous subsection
illustrates the computation of period by period costs for each environment in which end items operate. Also, the computation of period equivalent costs per environment and a total logistics policy period equivalent cost are detailed. This type of data can provide the logistics decision maker with a valuable measure of performance for evaluating end items operating in different environments and under different logistics policies. The second performance measure provided by the model is availability. The model provides the availability of end items in each environment and a total population availability. Again, the logistics decision maker has valuable data for measuring performance.

Secondary measures of performance include inventory demand profiles, maintenance facility projections, and manpower projections as determined by the model. Knowledge of inventory demand profiles becomes important if there are warehousing constraints or procurement lot sizing constraints. Maintenance facility projections and manpower projections become important in the face of limited space for maintenance facilities and limited manpower for maintenance functions.

The primary measures of performance can also function as constraints. If a budget constraint is imposed, the logistics strategy must be varied to meet the constraint.
Unless excellent data is available for computing the cost of logistics policy, the cost performance measure is better used as a comparison tool when evaluating one logistics policy versus another. If a demand must be met a certain percentage of the time, then an availability constraint exists and logistics strategy must be varied to meet the constraint. Knowledge of inventory profiles, maintenance facility projections, and manpower projections again become important in the face of constraints such as budget or availability constraints.

3.4 USES OF THE MODEL.

The model should be able to satisfy many of the logistician's planning needs. In general, the model will generate the maintenance requirement demand of a finite population of repairable items. This will include spare parts requirements in the form of EOQ inventory level policies, manpower hours required to staff maintenance facilities, warehouse space required for spare parts inventories, the costs associated with the operation and maintenance of the designed logistics system, and the availability of units under the proposed logistics policies. The computerized version of the model produces the diagrams shown in Figure 3.11. The performance measures described in the previous section serve as output to be used by the logistician in judging the effectiveness
Manpower Requirements

Warehouse Requirements

Inventory Requirements

Availability

FIGURE 3.11. MODEL OUTPUT
of proposed logistics policy. These performance measures allow the logistian to evaluate the effects of cost and availability constraints. Also warehousing, personnel, and procurement policy constraints can be evaluated.

The use of various methods of spare parts inventory lot sizing may be evaluated by adding subroutines to the model that produce data similar to the EOQ routine already incorporated into the model. Also, warehouse and budget constraints could be considered versus varying methods of lot sizing. In situations where spare parts are manufactured in house, lot sizing of manufacturing batches could be planned using the spare parts requirements generated by the model.

The model is structured to handle more than one level of repair simply by specifying in the maintenance tree what type of repair facility is required for a specific repair. The model produces spare parts requirements based on the repair facility at which the repair must be made so that spare parts inventory requirements for separate levels of repair are totaled separately. By comparing the spare parts requirements at the various levels of repair, common spare parts requirements can be identified. This information can assist in the establishment of centralized procurement policies which could save on spare parts prices and procurement costs.
The model considers the MTTR associated with the repair being made at the specified repair facility. From this information, the expected demand on various repair facilities is calculated. Knowing these repair facility requirements can assist in the design and construction of, or alteration of, repair facilities. Knowing the requirements ahead of time would also help with staffing and training. Since nonsteady-state conditions are being evaluated, the characteristics of the repair channels can be adjusted to keep pace with the needs of the population. The same adjustments may be made to the spare parts inventory. Only enough inventory to meet the requirements will need to be procured.

The logistics decision maker can use the model as an aid in making traditional repair or replace decisions. By varying the retirement age of end items the user of the model can view the cause and effect relationships between retirement age and cost, availability, spare parts inventory requirements and maintenance facility space and manpower requirements. Decision variables besides the retirement age, such as the total number of units in the population may also be varied. The user of the model will observe that adjusting one decision variable in response to changes in another decision variable can lessen negative impact on the performance measures of the model.
Quality and its effects on the performance measures can be modeled by using the model to evaluate the different failure rates common to different quality equipment. Also the effects of various procurement policies on performance measures may be evaluated. The model could be used as a tool to forecast how many units would have to be procured each year in order to maintain a certain population size or a population growth rate. These capabilities, in conjunction with the model's ability to forecast maintenance requirements, make the model an excellent capital and operating budgeting tool.

In order to make the model easier for the logistician to use, procurement policy scenario generators are included. The generation of these scenarios means that in order to achieve more realistic scenarios, the user of the model does not have to input data at each time period. The computer is generating the period by period "realism". This scenario concept could be extended to make the model less cumbersome for the user and possibly more realistic in its outputs. See Sections 4.5 and 6.3 for discussions of model extensions.

Since the concept of nested Markov chains is applied, nonhomogeneous populations could be evaluated as long as all units within a particular chain possess similar failure characteristics, and as long as the same maintenance tree
can be attached to each end item. The populations could be called nonhomogeneous because of several factors: different brand names may be present, improved models may be procured as replacements for original units, or units may be employed in different environments. As a hypothetical example of the "different environments" idea, consider a scenario in which a logistician for a widespread military research division purchases 200 batteries in 1980. Half of the batteries are immediately placed in use at a research facility in Antarctica and half of the batteries are immediately placed in use at a research facility in Brazil, near the equator. In the proposed logistics model, the batteries sent to Antarctica would form a stream with a Markov chain of failure probabilities and the batteries sent to Brazil would form a separate stream with its own Markov chain of failure probabilities. The separate chains are required because the two sets of units would obviously have different failure rates. Batteries can last considerably longer in a tropical climate as compared with a frigid climate. The batteries would thus be operating in two different failure environments.

The concept of preventive maintenance may be handled by establishing a life cycle for the major component parts considered in the nested Markov chains. This "preventive maintenance" would take place in the form of replacing
major component parts at prescribed intervals. The model will not presently evaluate the concept of preventive maintenance. Extensions would be required.

With the division of the population into streams, each with its own Markov chain, a division of cost calculation is also accomplished. The costs for operating each stream of equipment are calculated, thus giving a comparison of costs between streams and failure environments within the population.

Finally, the model may be used to illustrate just how effective a logistician can be when the correct data base exists. The model will in effect be used as a demonstration of data requirements necessary for more efficient logistics modeling.

3.5 LIMITATIONS OF THE MODELING APPROACH.

In approaching the problem of maintenance requirements planning by investigating both transient and steady state modes of operation, two major limitations have been encountered. First, trying to model transient state conditions creates the need to consider an overwhelming number of possible combinations of events. The need for simplifying assumptions manifests itself. The second major limitation encountered in this transient state modeling approach is a problem probably encountered by all logistics model developers. All of the data necessary to make
accurate model maintenance requirements of repairable item populations is not readily available. A great deal of assuming, estimating, and extrapolating must take place.

The concept of the maintenance tree can serve as a limitation if complex populations are being evaluated. How big does one make the maintenance tree? How small should the components at the "bottom of the tree nodes" be? If a complex piece of machinery with hundreds or more repairable parts is being evaluated, the construction of a maintenance tree that will identify every stockable item may prove too large in scope for this model.

The multi-stream concept presents limitations when populations are evaluated that operate in many different failure environments or if a population is particularly long lived. In this type of situation a tremendously large number of streams of end items may be generated. Keeping track of data and outputting concise information for each stream would be difficult.

Choosing to avoid simulation of what happens when an end item fails and is removed from operation was a large simplifying decision. The repair phase can be a significantly expensive part of operating and maintaining a population of repairable items. This model would not be of much assistance in fine tuning repair processes.
Choosing to place the computerized version of this model on a personal computer created a limitation in the amount of data that could be considered. Thus, the number of end items, the number of maintenance tree nodes, the number of stockable items, and the number of failure environments that can be considered are limited. Implementing the present model on an IBM PC with 256 K memory proved to be a programming challenge. Also, in using a computer to calculate maintenance requirements, it must be remembered that there will be round off errors. Some of the round offs are forced by the method of programming, other round offs are inherent in the use of a computer. In large populations with extensive maintenance requirements, these round offs should have a negligible effect on output. In situations where small streams of end items exist with corresponding small maintenance requirements, the user of the model must take care in interpreting output provided by the model.

As long as the idea of a shortage cost is included in a model of this sort, there is going to be a problem with quantifying that cost. Using an arbitrary figure, such as shortage cost, in conjunction with other types of logistics costs, makes the overall logistics policy costs better suited for comparative purposes. Only in situations where the shortage cost may either be
omitted or quantified can such things as budget constraints be accurately assessed with a model of this type.

The limitations imposed by simplifying assumptions are discussed in the section on Assumptions, Section 3.3.2. Certain extensions of the model that may bypass these limiting assumptions and alleviate several of the other limitations imposed by the modeling approach taken are discussed in more detail in Sections 4.5 and 6.3.

3.6 SUMMARY OF THE MODELING APPROACH.

The modeling approach used in the development of this maintenance requirements planning model started with the establishment of the basic concepts upon which the model has subsequently been built. Two major concepts were determined as being conducive to the development of a model that could evaluate nonsteady-state phases of end item operation, those being the multi-stream concept and the maintenance tree concept.

The objectives of the research established the type of data that the model was to produce. In order to produce the data required with a model, assumptions had to be made. Some assumptions were necessary to keep the research within manageable proportions and some assumptions were necessary because of the inability of a mathematical model to emulate real life occurrences. The next step of the modeling procedure involved deciding what decision variables and
parameters must be evaluated in order to produce the data called for in the research objectives.

After defining the decision variables and parameters, the modeling approach called for the development of a set of mathematical equations. The equations represent the mechanical link between the decision variables, parameters, and other input data and the maintenance requirements generated as model output. The output data produced by the equations provide measures of performance which the logistics decision maker can use to compare the effects of operating environments and logistics policy decisions on the maintenance requirements of repairable end items. Based on the type of output produced by the final version of the model, a variety of uses for the model were established.

Once it was determined what the model could do, the final step of the modeling approach was taken. This final step involved taking a realistic look at the assumptions made and the methods used in constructing the model. This "look" helped to determine the model's limitations. The next chapter will take a look at the model in its final form and discuss the implementation of the model in the face of these limitations.
CHAPTER IV
MODEL IMPLEMENTATION

4.1 INTRODUCTION.

This chapter will discuss the data requirement generated by the model and try to illustrate just how worthwhile it is to collect good failure and repair data. The chapter also will show how that data is organized, by the model, for use with the assumptions and calculations detailed in Chapter 3.

Since the model is programmed on a microcomputer, there are certain hardware limitations. Possible ways to alleviate these limitations, as well as some of the limiting assumptions described in Section 3.3.2, are discussed. This discussion produces a host of ideas for model extensions. The description of these model extensions should give the reader a feel for the potential uses of the model.

A section on the level of application of the model, as it exists today, provides some insight as to who should use the model and how it should be applied. Ideas on the level of application of the model, if certain extensions are made, are included also. A summary of the limitations and potential of the model closes the chapter.
4.2 PROFILE OF DATA REQUIREMENTS.

The data requirement generated by this logistics model can become extensive. Since the transient state operation of repairable item populations is being evaluated, more detailed failure and repair data must be provided in order to produce maintenance requirements. Since different failure environments can produce different sets of failure and repair rates, failure and repair data requirements are multiplied as the number of failure environments increases. To support the maintenance tree concept and produce spare parts requirements, a great deal of bill of material type data is required. The model serves as an illustration of the trade off that exists between the realism of model output versus the amount of data required to produce results with the model. The amount of flexibility and the level of realism inherent in this model has resulted in a large data requirement. As can be seen in the discussions on simplifying assumptions in Section 3.3.2 and on model extensions in Section 4.5, a great deal more flexibility and realism could be added to the model. Many of these extensions would serve to increase the data requirement even further.

Besides requiring a large quantity of data, the data that is required is often difficult to obtain, or in many cases nonexistent. In order to obtain information on end
item availability, end item maintenance requirements, and logistics policy cost, the user of this model must devise methods of collecting or estimating this data. The data that must be input by the user is summarized in Table 4.1.

Data such as the period unit, the length of a period, and the length of a model run can be determined if the user of the model is familiar with inventory, cost, and availability reporting schedules for the organization within which the model is being applied. Some idea of the frequency of failures and the average time spent in repair for end items and components will also assist in choosing period length. Generally, MTTR's should be less than the period length and MTBF's should be longer than a period length. Data such as the demand for end items or the required availability of end items will probably be specified by someone other than the logistician and can be treated as given data.

Some of the cost data required, such as the first cost of end items and spare parts is readily available to the logistician. The interest rate also should be relatively easy to obtain. The rate used should represent the time value of money based on a rate of return established by existing market conditions. Other cost data such as book values and salvage values of end items, procurement costs for end items and spare parts, repair costs, and cost of
TABLE 4.1. INPUT DATA REQUIRED BY THE MODEL

Period Unit
Length of Period
Length of Model Run

End Item Cost Data:
  First Cost
  Salvage Value upon Fatal Failure
  Book Value at Retirement
  Procurement Cost
  Average Repair Cost
  Average Shortage Cost
  Inventory Holding Cost for Stockable Items
  Interest Rate

Bill of Materials for End Item

Stockable Item Data:
  Part Number
  First Cost
  Procurement Cost
  Warehouse Space Requirement
  Inventory Holding Cost
  Lead Time

Number of Failure Environments

"Bottom of Tree" Component Failure Data (Per Environment):
  Cumulative Distribution Failure Probability
  MTBF
  MTTR
  Repair Level

Demand for End Items per Environment

Retirement Age for End Items per Environment

Age of Existing End Items per Environment
warehousing should be obtainable through calculation or in-house sources. Determining the cost of repair, as it is defined in this model, presents more of a challenge. Since the cost of repair represents the costs incurred during the time that elapses between failure of the end item and the time the end item returns to service, quite a bit of cost data may have to be collected before a representative repair cost per unit time can be determined.

The one piece of cost data that could be especially difficult to quantify is the shortage cost. If the population of repairable end items being evaluated is operating in a situation where shortages of end items simply result in lost revenues, then the shortage cost is easily quantifiable. On the other hand, if shortages of end items require emergency actions, noncompletion of missions, injury, or death, the establishment of a monetary value for shortage cost can be difficult. The user of the model must establish this cost such that if shortages do occur, the cost of the logistics policy in force is penalized sufficiently. In these cases, the shortage cost is serving as a reminder of the relative severity of a shortage of end items. Here, the magnitude of the shortage penalty is more important than the actual value of the shortage penalty.
In order to construct a maintenance tree for the end item and evaluate spare parts requirements, knowledge of the bill of materials comprising the end item is a must. This information should be obtainable from manufacturer sources. The arrangement of the components in the maintenance tree is also a data input decision that must be made by the user of the model. The tree must be constructed so as to accurately reflect the dependent and independent components of the end item and also provide information pertinent to required inventory levels of spare parts, warehouse space required at various repair levels, and repair facility capacities.

The data that is perhaps the key to using this model is failure data and repair data. If it cannot be determined how often an end item will fail, and how long it will take to repair it, then it becomes nearly impossible to predict how large a population of end items should be maintained. If the same failure and repair data is not available for the end item components that fail, then spare parts requirements and repair facility requirements cannot be readily estimated.

Failure rates can be estimated if a mean time between failures (MTBF) and an accompanying probability distribution can be determined for end items and end item components that fail. A mean time to repair (MTTR) for the
end item can be determined only after component MTTR's have been estimated. These component MTTR's must take into account everything that might happen to an end item between the time that the component causes an end item failure and the time that the end item returns to operation.

The user of the model must also know how failure environments affect the failure rate and repair rates of end items and components. A whole new set of failure and repair data may be required for each failure environment.

Where does the logistcian obtain failure and repair data? This is a major issue any time maintenance requirements planning is performed. Possible sources of information include: in-house maintenance records; outside source maintenance records; manufacturer information or test data; or independent source test data. When data on one component is lacking, the known failure and repair data from similar components may be applied. Worst case failure and repair data could be constructed by applying very conservative failure and repair rate estimates to components.

Even though there are several sources of failure and repair information, the quality and the quantity of information available remains low. Manufacturers either do not make enough test data on component failure rates
available, or manufacturers do not test component failure rates. Whatever the case may be, the logistian does not generally receive a great deal of manufacturer assistance in the determination of reliability and maintainability characteristics of end items and components.

Repair facility records hold forth the promise of being a good source of data that can be used to establish MTBF's and MTTR's. In the past, repair facilities have generally been notorious for poor record keeping. With the advent of bar codes and other electronic data collection systems, it is becoming possible for repair facilities to maintain large, thorough data banks. The maintenance history of end items and their components can be recorded with electronic sensing devices, and then stored in computer related memory devices. Depending on the type of data collection system used, the storage of the collected data may be accomplished automatically or manually.

It is hoped that models, such as the one described in this paper, will establish the importance of having good failure and repair records available. It is also hoped that models, such as this one, will specify what kind of repair data and what kind of failure data should be maintained. The data requirements established by this and other logistics models should aid in the construction of electronic data collection systems that are built around
the specific needs of the maintenance requirements planners, and are conducive to proper use in repair facilities.

4.3 COMPUTATIONAL BASIS OF MODEL.

The model can be looked upon as a system of generators and aggregation routines. After being provided with input data by the user, the model generates the maintenance requirements for streams of end items, sums the results and then generates maintenance requirements for the entire population of repairable end items. In the process, the model computes the cost of the associated logistics policy and the availability of the population of end items. The operation of the model is structured as follows:

1) user inputs data for model generators
2) model generates stream by stream failure characteristics and maintenance requirements
3) model sums stream by stream results
4) model generates period maintenance requirements availability and logistics policy costs
5) model sums period by period results and returns to step 2 until last period is reached
6) model generates charts and graphs depicting period by period maintenance requirements per failure environment, logistics policy costs and availability

See the flow chart in Figure 4.1. Figure 4.2 gives a more detailed picture of the operation of the family of generators that make up the model.

As the user inputs data, several scenario generators are being "seeded". By specifying a retirement age, a generator that removes streams of end items from operation as they reach the appropriate age is seeded. Specifying the chance of fatal failure for the end items seeds a generator that reduces the size of the population of end items in response to the estimated number of fatal failures that occur within a given period.

End items are procured and new streams formed at specified intervals and in specified amounts after the user inputs data for the procurement policy scenario generator. By supplying an MTBF and failure curve shape for each component, the user is seeding the generator that will produce the probabilities of failure of various components. Another subroutine then combines the failure probabilities of the components to produce the probability of failure of the end item.
INPUT
user "seeds" generators

model computes stream failure rates maintenance requirements

\[ \sum \text{stream by stream data is summed} \]

model computes period maintenance requirements, availability, and cost

\[ \sum \text{period by period data is summed} \]

end of model run?

No

Yes

model produces summaries and total cost

FIGURE 4.1. MODEL OPERATION MACRO FLOW CHART
**Figure 4.2. Model Operation Micro Flow Chart**
Cost of logistics policy is generated after the user inputs the necessary cost data. Once period logistics policy has been computed, the cost generator computes present values of the period logistics policy costs and then sums these costs. After the period costs have been summed, the cost generator then computes a period equivalent cost of the logistics policy. This period equivalent cost represents the average per period cost for the length of the model run. The user of the model seeds the cost generator by inputting cost data and an interest rate representing the time value of money.

Additional generators compute spare parts requirements by repair level and specify inventory levels and ordering policies using economic order quantity concepts. Through the process shown by the flow chart in Figure 4.2, these generators perform various computations that result in the outputs noted in the figure. The computations are based on the concepts, assumptions, and calculations detailed in Section 3.3.

4.4 COMPUTER RELATED LIMITATIONS.

By implementing this model on a personal computer (PC), three major PC related limitations were encountered: memory, speed, and display. Central Processing Unit (CPU), Basic Interpreter, diskette, and screen display
characteristics of the PC played a part in the limitations encountered. An IBM PC with 256K of CPU memory and dual floppy disks was utilized.

Techniques used to program the maintenance requirements planning model resulted in an extremely long computer program (coded in Basic computer language). Because of Basic Interpreter capacity limitations and because of CPU memory limitation, the program has been split into several subprograms. When running the model, the subprograms are "chained" together. This means that only one part of the model is actually loaded into the CPU at a time.

Also, because of the Basic Interpreter and the CPU memory limitation, much of the data generated by the model must be stored in files on the floppy disk, rather than in arrays within the CPU. The potential of the model to create a large number of files raises the possibility of a diskette capacity limitation. Only a limited number of files can be stored on any memory device. There are many devices with more storage capacity than floppy disks. The result of the memory limitations is that only a small number of failure environments can be evaluated, the number of stockable items per "bottom of the tree" component is restricted, the size of the maintenance tree (number of nodes) is limited, and the number of streams of end items
that can be created is limited. The memory limitations could be eased by adding capacity to CPU memory and utilizing hard disks instead of floppy disks.

The processing speed of personal computers combined with the fact that programs are chained together and data files are used, cause the model to run slowly. Data files must be used because the model tracks such a great number of variables. Reading and writing these variables to and from disk files can take a considerable amount of time. The only computation within the model that can take longer than five seconds is the availability computation. If populations are evaluated where there is a significant difference between the total number of end items in a particular environment and the demand for end items in that environment, computation times can run as long as thirty seconds for the availability routine alone. These actual computation times could be improved by compiling the Basic programs that make up the model and running the model using Compiled Basic. The use of Compiled Basic would also avoid some of the memory limitations imposed by Interpreter Basic. (The version of Interpreter Basic used for this research only utilized 64k of CPU memory.) Adding CPU memory capacity could eliminate the need for data files and chained programs and significantly decrease the time required for the computer to complete a run.
The display limitation occurs because of the display screen size and the resolution of the average monitor. It is difficult to accurately depict the maintenance tree on one screen or the output data, for such things as spare parts requirements or node by node failure probabilities, on a single screen. If the user of the model wishes to study in detail, the maintenance requirements and failure probabilities of each stream of end items, he or she will be forced to print out the information desired. Printing information from the PC will also serve to slow the execution of the model, especially if printing must be done as each stream is evaluated within a period.

4.5 MAINFRAME IMPLEMENTATION AND OTHER EXTENSIONS

The limitations of implementing the model on a personal computer all point toward the use of larger, faster computing equipment. A mainframe implementation of the model would provide enough memory capacity so that the use of chained programs and data files could be avoided. A mainframe implementation would provide rapid access to any disk files that did have to be used. These improvements would result in a faster running model that could handle larger end item populations, more failure environments, and an expanded maintenance tree. As the length of the model run (number of periods evaluated) increases, it is likely
that the number of streams of end items will continue to increase (as new end items are procured). The added capacity of a main frame implementation would increase the number of periods that could be evaluated.

With the additional memory inherent in a main frame computer, not only can the model run faster, but hardcopy printouts can generally be produced faster since main frame printers are faster than PC printers. The display limitation will not disappear if a main frame implementation occurs. The video monitors used for personal computers and main frames are usually similar in size.

If the model were used on a main frame it is likely that data for more than one end item population could be input at a time, thus making data input a more efficient process. Also, more flexibility could be built into the model, since with additional memory capacity, more scenario generators could be added. Generators that would allow the evaluation of populations of end items, where the end items are rotated from environment to environment, would represent a model extension. This extension could be especially valuable in situations where end items are rotated into and out of storage. Other scenario generators that would represent extensions of the present model could provide inventory lot sizing utilizing techniques besides
EOQ. Also, a scenario generator could be added that when programmed would change the demand or costs associated with end items as the model advances from period to period.

Generators that would automatically change the input data, according to preprogramming by the user of the model, and send the model through another run, would save additional time for the user. The addition of preventive maintenance scenario generators would allow the user to evaluate the effects of performing maintenance on some components before they failed. This extension would, of course, include the capability to change failure probabilities when preventive maintenance was performed.

A main frame implementation would facilitate several model extensions that would relieve some of the restrictive assumptions discussed in Section 3.3.2. For example, additional memory would allow the evaluation of situations where all stockable items are not required every time a failure occurs. This type of situation exists with a car battery, where new clamps and cables are not required each time the battery fails. In most end items the failure of some components does not always signal the failure of the end item. An extension of the model could consider these noncritical components and their contribution to the cost of maintaining a population of end items. The evaluation of parallel or redundant systems of components would
represent a major extension of the model.

The extensions listed above, made possible by main frame implementation, would add to the flexibility and the realism of the model output. Additional flexibility provided by main frame implementation would allow the model to pull data from a central data base. The concept of placing maintenance records on computer through the use of electronic tracking devices is discussed in Section 4.2. It would be easier for the model to become a part of a Material Requirements Planning system if main frame implementation occurred. See the next section for further discussion on the MRP characteristics of this model.

4.6 LEVEL OF APPLICATION.

The questions of, how should this model be used, and who should use this model, must be answered. The model is seen as having application in commercial, public, or military settings. In a commercial environment, the model could be used for fleet sizing and maintenance requirement planning for a fleet of forklift trucks. The model would have applications in local, state, or federal government settings where fleets of vehicles or machinery are maintained. The evaluation of the maintenance requirements for equipment, such as two way radios, could be performed by the model. In military settings, any group of
repairable items could be evaluated. The case studies in Chapter 5 all illustrate military applications of the model.

The model produces much of the information that is required by Materials Requirement Planning systems. Such information includes: the number of end items required to meet a demand, the number of spare parts required to support the end item, the location of end items (by failure environment), and the location of repair parts (by repair facility). Since the model has the potential to be implemented on a main frame computer, it could be tied in with an existing MRP system. This would allow the MRP system to track the location and availability of machinery and vehicles, as well as production items. Actually, the model could serve as a stand alone MRP system for the population of end items that it is evaluating, once a logistics policy has been determined. In this case a more appropriate name for the system would be Maintenance Requirement Planning, which is a descriptor that has been used throughout this document.

The above examples are intended to illustrate that use of the model is limited only by the imagination of the user. The answer to the question of who should use the model has a more limited scope. Since the model provides information on the availability of, the maintenance
requirements of, and the operation cost of a population of repairable items, the user of the model should be a person that has some input into determining the size of end item populations, inventory levels of spare parts, and procurement policies. That person should be in a position to use the model as a planning tool.

The model would probably receive its fullest usage if utilized by the staff in charge of the highest level of repair evaluated on the model. In Case Study 1, in Chapter 5, the depot level of repair represents the highest level of repair, and the lower levels of repair represent a group of repair facilities that report to that depot. The model is not presently conducive to use at levels higher than the manager of the depot in the case study. Including too many groups of repair facilities in the model will make the determination of repair costs and MTTR's very difficult, because different depots may have significant differentials in repair costs and MTTR's due to geographic location. If one depot and its family of repair facilities are evaluated, the degree of accuracy of average repair costs and MTTR's, as applied at each level of repair, will be greater.

With some modification, the model could receive some usage at much higher levels of planning. The bottom of the tree nodes of the maintenance tree could represent
populations of end items, with higher nodes representing systems or groups of populations. By assigning appropriate failure and repair data to the populations of end items, the model would produce information on the rates of failure of, not only the populations of end items, but of systems of end items. The spare parts output would represent the number of spare end items to be kept on hand and the availability output would represent the availability of the entire system being evaluated. This macro-application of the model would take some development, but it is an example of how very high level decision makers could use such a model.

4.7 SUMMARY.

This chapter has expounded on the applications of the model and reemphasized some of the limitations. The intent was to give a clearer picture of the capabilities and potential of the model. The section on data requirements points out that the price paid for the flexibility and realism inherent in the model is a tremendous data requirement. The potential for the use of the model as a logistics planning tool should provide some impetus to data collection efforts. The case studies described in Chapter 5 should further illustrate what kind of logistics forecasting can be done with good data.
This chapter outlined how the model uses the data supplied by the user to perform logistics forecasting. The present model implementation is limited by the hardware on which it is being used, but the potential for model expansions through a main frame implementation is great. The expansions would include the ability to handle more data and produce results at a faster speed. Expansions in computing ability would open the door for model extensions that would alleviate many of the limiting assumptions applied.

The many extensions of the model discussed would identify the model as a potential source of artificial intelligence, if the extensions were implemented successfully. When programmed with the right data, and armed with the appropriate optimization techniques, the model could detail logistics policy for logistics planners. Keep in mind, however, that the model at this time is a conceptual model that depends on "what if" gaming interface with the user of the model, in order to evaluate logistics policy.
CHAPTER V
EMPIRICAL ANALYSIS

5.1 INTRODUCTION.

In order to illustrate the output capabilities of the model, Case Study 1 was developed, and the corresponding data was input into the model. A description of the case population and a description of the data base typical to that population are contained in this chapter. Following that description is an analysis of the maintenance requirements generated by the model for that case population. The format and validity of results generated here represent the type of results that the model can produce for a case population when appropriate data is available.

In order to more fully illustrate the "what if" gaming capabilities of the model, two additional case study scenarios (Case Studies 2 and 3) are developed in Sections 5.5 and 5.6. Case Study 2 illustrates a scenario in which a "what if" gaming procedure can be used to obtain least cost logistics policies and meet availability requirements by varying procurement policies. Case Study 3 illustrates a scenario in which the model can be used to compare the effects of end item quality on maintenance requirements and availability for the case population.
5.2 DESCRIPTION OF CASE POPULATION.

The case population being evaluated in Case Study 1 is a group of 220 Side Loadable Warping Tugs (SLWT's). The SLWT is a component of the Container Offloading and Transfer System (COTS) utilized by the U.S. Navy. The COTS is a deployable system designed to provide seaborne military forces of the U.S. Navy with logistics support during and subsequent to entry on land masses where suitable port facilities are not available. The logistics support provided is basically the unloading (from ships) and transfer to shore of the required quantities of bulk dry cargo and vehicles. The COTS is designed to operate beginning on the day after land entry by military forces (D-day + 1) to D-day + 180 or longer.

The SLWT is a powered causeway section that can serve several functions as a part of COTS. When equipped with a winch and A-frame, one of the major functions of the SLWT is to assist in the construction of the causeway on piers that connects ship to shore. The SLWT can also assist in the mooring of vessels, craft salvage operations, or the transport of shipping containers from ship to shore. Figure 5.1 depicts the SLWT. The case study developed from this point on is fabricated and does not necessarily represent real events, nor does the data used necessarily
FIGURE 5.1. SIDE-LOADABLE WARPING TUG
represent exactly the present SLWT used by the Navy.

Being a seagoing vessel, the SLWT is virtually immune to fatal failure when maintained properly. An exception to this is when the SLWT is operating in a militarily hostile environment where an SLWT may be damaged irreparably by enemy attack. In Case Study 1 a population of 220 SLWT's is evaluated with some of the units operating in a support area environment that is removed from hostile military action, and the rest of the units operating in a combat zone.

The combat zone environment differs from the support area environment in two ways. The major difference between the two environments is in fatal failure probabilities. The SLWT's operating in the Support Area Environment have a very slim chance of fatal failure, which is represented by a mean time between fatal failures of 100,000 operating hours per unit. The cumulative rate of fatal failure for these SLWT's follows an Increasing Exponential function, which means that early in the life of these SLWT's there will be an almost nonexistent probability of fatal failure. On the other hand, SLWT's operating in the Combat Zone Environment have a mean time between fatal failures of 7200 operating hours per unit. The cumulative rate of fatal failure for these SLWT's follows a Uniform distribution, which means that there is an equal chance of fatal failure.
within each time period. This type of fatal failure pattern is the result of the fact that fatal failure occurs mainly due to enemy attack.

The second major difference between the two environments is that SLWT's work a different number of hours per day in each environment. In the Support Area Environment, an SLWT works an average of 8 hours per day and in the Combat Zone Environment, an SLWT works an average of 12 hours per day. It is this difference in hours worked per day that gives the various components ("bottom of the tree" nodes) of the SLWT a different probability of failure in each environment.

As an example of the difference in failure rates created by the differing number of hours worked per day, consider the case of the "bottom of the tree" node representing a seawater pump. Keep in mind that the SLWT's are equipped identically regardless of which environment they operate in. It has been determined that the type of seawater pump used has an MTBF of 5000 hours.

\[
\text{MTBF support} = \frac{5000 \text{ hours}}{8 \text{ hours/day}} = 625 \text{ days}
\]

\[
\text{MTBF combat} = \frac{5000 \text{ hours}}{12 \text{ hours/day}} = 417 \text{ days}
\]

The logistics group that supports the SLWT's would like to know what kind of maintenance requirements the
total population of SLWT's will generate in 30 day periods over the course of a year. This length of model run of 1 year should cover the total length of the period over which the services of the population of SLWT's will be required. The population of SLWT's will be evaluated as if the 220 end items were procured in a block procurement at time = 0 and then operated for the next 12 consecutive periods.

When an SLWT requires repair, there are three levels of repair that will apply. Organizational level repairs will be performed on board the SLWT, with the spare parts necessary to perform these repairs carried on board. Intermediate repairs will be performed by a repair facility set up on shore, with that facility stocking the necessary spare parts. The third level of repair, depot level repair, will be necessary only in the event of serious failures. The depot stocks its own parts. The depot is a centrally located facility, so when a level 3 failure occurs, the SLWT must be transported to the depot for repair. It is assumed that, regardless of the environment in which the units operate, they require the same levels of repair dependent on the type of component failure that occurs.

In order to get some feel for the levels of spare parts to maintain at each repair level, the logistics support group will run the model in the EOQ mode. This
means the model will not only produce the period by period spare parts demand, but will generate an EOQ, a warehouse requirement based on the EOQ, and the total inventory cost of following the prescribed optimal EOQ policy.

Since the SLWT's are virtually indestructible due to natural causes, it has been determined that the retirement age of the units should be 500 periods or roughly 40 years. It has also been established that a total of 140 SLWT's must be operating in order for the Support Area operation to succeed and that a total of 60 units must be operating in order for the Combat Zone operation to succeed.

5.3 DATA BASE FOR CASE IMPLEMENTATION.

The set of information contained in Table 5.1 represents general population data that was input into the model for Case Study 1. Please keep in mind that good solid data was not available and a great deal of the data was fabricated around information that was available on the SLWT. The cost data may be significantly different from the actual costs involved with the SLWT.

The maintenance tree in Figure 5.2 represents the hierarchical structure of the SLWT. This tree is fairly representative of the actual SLWT. Tables 5.2 and 5.3 give the MTBF, MTTR, Repair Level, and Failure Curve data for each bottom of the tree node in each failure environment. Again, this particular set of data may be fairly
TABLE 5.1 GENERAL POPULATION DATA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period Parameter</td>
<td>Days</td>
</tr>
<tr>
<td>Period Length</td>
<td>30</td>
</tr>
<tr>
<td>Length of Model Run</td>
<td>12</td>
</tr>
<tr>
<td># of Failure Environments</td>
<td>2</td>
</tr>
<tr>
<td>First Cost per SLWT</td>
<td>$350,000</td>
</tr>
<tr>
<td>Salvage Value per SLWT (upon fatal failure)</td>
<td>$ 8000</td>
</tr>
<tr>
<td>Procurement Costs</td>
<td>$ 10000</td>
</tr>
<tr>
<td>Repair Costs per SLWT per Day</td>
<td>$ 500</td>
</tr>
<tr>
<td>Shortage Cost per Day</td>
<td>$ 30000</td>
</tr>
<tr>
<td>Time Value of Money</td>
<td>10%</td>
</tr>
</tbody>
</table>

Model Mode                                      Proposed Population
Spare parts and Warehouse Requirements:          EOQ
Procurement Policy                              one initial block procurement
Procurement Amount                              220
Divide Procurement                              Support: 144    Combat: 76

Failure Environments:                           Support Area     Combat Zone
Retirement Age per SLWT                         500 periods      500 periods
Retirement Book Value                           $15000/SLWT      $15000/SLWT
Demand for SLWT's                               140              60
FIGURE 5.2. MAINTENANCE TREE FOR CASE STUDY 1
### TABLE 5.2 NODE DATA FOR SUPPORT AREA ENVIRONMENT

<table>
<thead>
<tr>
<th>Node #</th>
<th>Node Name</th>
<th>Repair Level</th>
<th>MTBF (days)</th>
<th>MTTR (days)</th>
<th>Failure Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Engine Oil Cooler</td>
<td>1</td>
<td>1000</td>
<td>1.8</td>
<td>5</td>
</tr>
<tr>
<td>27</td>
<td>Freshwater Pump</td>
<td>2</td>
<td>250</td>
<td>1.0</td>
<td>3</td>
</tr>
<tr>
<td>28</td>
<td>Seawater Pump</td>
<td>2</td>
<td>625</td>
<td>1.2</td>
<td>3</td>
</tr>
<tr>
<td>29</td>
<td>Hydraulic Pump</td>
<td>1</td>
<td>1000</td>
<td>1.2</td>
<td>3</td>
</tr>
<tr>
<td>32</td>
<td>Eng.Cool.Heat Exch.</td>
<td>2</td>
<td>1000</td>
<td>1.8</td>
<td>4</td>
</tr>
<tr>
<td>33</td>
<td>Freshwa.Heat Exch.</td>
<td>1</td>
<td>1000</td>
<td>1.8</td>
<td>4</td>
</tr>
<tr>
<td>34</td>
<td>Hyd.Fluid HeatExch.</td>
<td>1</td>
<td>1000</td>
<td>1.8</td>
<td>4</td>
</tr>
<tr>
<td>52</td>
<td>Pres.Reducing Valve</td>
<td>1</td>
<td>500</td>
<td>0.8</td>
<td>3</td>
</tr>
<tr>
<td>53</td>
<td>Dir. Control Valve</td>
<td>1</td>
<td>125</td>
<td>1.2</td>
<td>3</td>
</tr>
<tr>
<td>54</td>
<td>Steering Motor</td>
<td>2</td>
<td>375</td>
<td>1.8</td>
<td>3</td>
</tr>
<tr>
<td>58</td>
<td>Filter</td>
<td>1</td>
<td>75</td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>59</td>
<td>Starter</td>
<td>1</td>
<td>312</td>
<td>2.0</td>
<td>3</td>
</tr>
<tr>
<td>62</td>
<td>Auto. Lubrication</td>
<td>1</td>
<td>188</td>
<td>1.0</td>
<td>5</td>
</tr>
<tr>
<td>63</td>
<td>Timer</td>
<td>1</td>
<td>94</td>
<td>2.4</td>
<td>5</td>
</tr>
<tr>
<td>64</td>
<td>Manifold</td>
<td>2</td>
<td>1250</td>
<td>15.0</td>
<td>3</td>
</tr>
<tr>
<td>65</td>
<td>Solenoid</td>
<td>1</td>
<td>94</td>
<td>1.2</td>
<td>5</td>
</tr>
<tr>
<td>92</td>
<td>Waterjet Pump</td>
<td>3</td>
<td>625</td>
<td>12.0</td>
<td>3</td>
</tr>
<tr>
<td>93</td>
<td>Discharge Elbow</td>
<td>2</td>
<td>1250</td>
<td>11.0</td>
<td>5</td>
</tr>
<tr>
<td>94</td>
<td>Steerable Nozzle</td>
<td>2</td>
<td>625</td>
<td>12.0</td>
<td>3</td>
</tr>
<tr>
<td>107</td>
<td>Booster Pump</td>
<td>2</td>
<td>375</td>
<td>0.8</td>
<td>3</td>
</tr>
<tr>
<td>108</td>
<td>Fuel/Wa. Separator</td>
<td>1</td>
<td>188</td>
<td>1.0</td>
<td>5</td>
</tr>
<tr>
<td>112</td>
<td>Inverter</td>
<td>1</td>
<td>250</td>
<td>0.5</td>
<td>5</td>
</tr>
<tr>
<td>113</td>
<td>Battery</td>
<td>1</td>
<td>125</td>
<td>0.1</td>
<td>3</td>
</tr>
<tr>
<td>114</td>
<td>Alternator</td>
<td>1</td>
<td>250</td>
<td>2.4</td>
<td>5</td>
</tr>
<tr>
<td>118</td>
<td>Hydraulic Motor</td>
<td>2</td>
<td>125</td>
<td>0.8</td>
<td>5</td>
</tr>
<tr>
<td>119</td>
<td>Hydraulic Pump</td>
<td>2</td>
<td>125</td>
<td>1.6</td>
<td>3</td>
</tr>
<tr>
<td>120</td>
<td>Cable</td>
<td>1</td>
<td>6250</td>
<td>0.5</td>
<td>5</td>
</tr>
<tr>
<td>123</td>
<td>Engine On/Off</td>
<td>1</td>
<td>1250</td>
<td>0.1</td>
<td>5</td>
</tr>
<tr>
<td>124</td>
<td>Throttle</td>
<td>1</td>
<td>2625</td>
<td>1.0</td>
<td>5</td>
</tr>
<tr>
<td>125</td>
<td>Steering Lever</td>
<td>1</td>
<td>2625</td>
<td>0.8</td>
<td>5</td>
</tr>
<tr>
<td>126</td>
<td>Clutch Lever</td>
<td>1</td>
<td>2625</td>
<td>0.8</td>
<td>5</td>
</tr>
</tbody>
</table>

Repair level 1 = Organizational Level Repair  
Repair level 2 = Intermediate Level Repair  
Repair level 3 = Depot Level Repair
TABLE 5.3 NODE DATA FOR COMBAT ZONE ENVIRONMENT

<table>
<thead>
<tr>
<th>Node #</th>
<th>Node Name</th>
<th>Repair Level</th>
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<th>MTTR (days)</th>
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</table>

Repair level 1 = Organizational Level Repair
Repair level 2 = Intermediate Level Repair
Repair level 3 = Depot Level Repair
representative of the SLWT, but can by no means be considered to be highly accurate. The failure data contained in Tables 5.2 and 5.3 represents the set of data that will prove to be the most difficult to obtain regardless of the type population of end items being evaluated. This data can be assumed to have been obtained from the performance of like components in other populations of end items, or in some cases, from data provided by the manufacturer of the component.

Tables 5.4 and 5.5 contain the inventory data that was input for each bottom of the tree node. This data, of course, is required for the generation of spare parts requirements using the EOQ model. If the model is extended to include other inventory lot sizing techniques, some different types of inputs may be required.

5.4 DESCRIPTION OF CASE STUDY 1 RESULTS.

The model outputs a wealth of information, as evidenced by the tables in Appendix 1, Tables 5.6 through 5.13, and Figures 5.3 through 5.6. These tables and figures will be analyzed in this section. Suggestions for performing sensitivity analysis and uses of the output will be discussed.

5.4.1 Maintenance Requirements Generated. As defined in Section 5.2, the primary reason for running Case Study 1 was to determine the maintenance requirements generated by
### TABLE 5.4 STOCKABLE ITEMS INPUT DATA

<table>
<thead>
<tr>
<th>Node</th>
<th>Part Name</th>
<th>Part Name</th>
<th>QY</th>
<th>WH</th>
<th>PR</th>
<th>PC</th>
<th>HC</th>
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</table>

QY = # of stockable items that must be replaced when failure occurs.

WH = cubic feet of warehouse space required per stockable item.

PR = purchase price per stockable item.

PC = procurement cost per procurement of stockable items.

HC = storage cost per stockable item per period.

LT = order to receipt lead time for stockable items.
TABLE 5.5 STOCKABLE ITEMS INPUT DATA

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<tr>
<th>Node #</th>
<th>Part #</th>
<th>Part Name</th>
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<th>WH</th>
<th>PR</th>
<th>PC</th>
<th>HC</th>
<th>LT</th>
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</table>

QY = # of stockable items that must be replaced when failure occurs.
WH = cubic feet of warehouse space required per stockable item.
PR = purchase price per stockable item.
PC = procurement cost per procurement of stockable items.
HC = storage cost per stockable item per period.
LT = order to receipt lead time for stockable items.
the case population of SLWT's. This purpose is satisfied by the tables in Appendix 1, which represent end of the period summaries of the spare parts demand generated by the total population of SLWT's. Each table identifies the stockable item (spare part) by part number and by the bottom of the tree node to which that part is attached. The summary also displays the EOQ for each part, and the warehouse requirement and total cost generated if that EOQ policy is adhered to. The EOQ and Total Cost equations are defined in Section 3.3.5.6.

The location at which each stockable item should be stocked is identified by including the repair level number. At the bottom of each summary is the total cubic feet of warehouse space required at each repair level. The twelve period summary charts give the logistician a tool to use in planning his stockable item ordering schedule to assure that the proper repair facilities are stocked at a level that should satisfy the maintenance requirement for spare parts generated by the population of SLWT's.

Tables 5.6 and 5.7 are summaries of the spare part demand for stockable items attached to Nodes 107 and 108. Here, the demand is broken down by environment. A plot of the period by period demand (Figure 5.3) mirrors, to some extent, the plots of period by period point probabilities of failure of the respected nodes in their respective
<table>
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TABLE 5.7 PERIOD SPARE PARTS DEMAND FOR NODE 108

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FIGURE 5.3. PERIOD SPARE PARTS DEMAND
environments. The plots of period by period point probabilities of failure are shown in Figures 5.4 and 5.5. The spare parts demand, for end items operating in the combat zone, will not exactly mirror point failure probabilities for the Combat Zone because there is a shrinking number of SLWT's in operation each period.

Table 5.8 contains information that will assist in the staffing of the repair facilities. Information supplied by the model includes the number of man-days of repair time per period required at each level of repair by the total population of SLWT's. As can be seen from the table, there are significant period to period fluctuations in the expected man-days required. Having some idea of expected repair time requirements will help prevent repair delays due to staffing shortages, or will help prevent overstaffing due to sudden drops in repair demand.

5.4.2 Failure Analysis. Tables 5.9 and 5.10 list the period by period probabilities of failure of selected nodes. As shown in the maintenance tree for the SLWT, Nodes 107 and 108 combine to give the failure probability for Node 23. Plots of the point probabilities and cumulative probabilities of failure for Nodes 107 and 108 (Figures 5.4 and 5.5) illustrate the effects that the choice of failure curve had on the failure patterns of these two particular nodes. The plot of the point
TABLE 5.8  PERIOD BY PERIOD MANPOWER REQUIREMENTS SUMMARY

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<th>Period</th>
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<th>Repair Level 2 (man-days)</th>
<th>Repair Level 3 (man-days)</th>
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TABLE 5.9 PERIOD POINT PROBABILITIES OF FAILURE
FOR NODES 108 AND 107

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FIGURE 5.4. PROBABILITY OF FAILURE PLOTS
FIGURE 5.5. PROBABILITY OF FAILURE PLOTS
FIGURE 5.6. PROBABILITY OF FAILURE PLOTS
probabilities of failure for Node 23 (Figure 5.6) illustrates the additive effects of Nodes 107 and 108 on Node 23.

It is interesting to note in the plot of point probabilities of failure for Node 1 (the end item or SLWT) that the failure rate tends to approach a steady state. These plots are graphs c. and d. in Figure 5.6. Perturbations in the curve are caused when parts experience accelerating failure rates according to the failure distribution applied to those particular parts. For instance, many of the bottom of the tree components were identified as components whose failure characteristics were similar to a bathtub function. Thus, a high initial failure rate is experienced followed by a sizable drop in failure rate. Sudden rises and falls in the Node 1 plot can be attributed to the fact that many components went through similar phases of their failure rate life cycle at the same time.

In comparing the plots of Node 1 point probabilities of failure for each of the two failure environments (Figure 5.6), it can be seen that the failure environment with the higher failure rate, Combat Zone, seeks a steady state sooner and at a higher level of failure than does the environment with the lower rate of failure. Frisch [5] makes this point when comparing items with different
quality, i.e., different failure rates.

5.4.3 Availability of SLWT's. Additional information output by the model includes the availability of SLWT's in their respective environments. By viewing Table 5.11 it can be seen that by the 10th month the SLWT population in the combat zone is operable less than 14% of the time. This can be attributed to the fact that because of fatal failures, the number of SLWT's operating in the Combat Zone has dropped below the demand figure of 60 by the end of period 10. The number of SLWT's in operation per period is listed in Tables 5.12 and 5.13 under the headings "# Units Start" and "# Units End".

By referring to Table 5.12 it can be seen that the number of units failing fatally has no effect on the availability of units operating in the Support Area environment because no fatal failures occur during the model run. The initial number of SLWT's assigned to this environment (144) is very close to the demand number of 140. The low availability during certain periods can be attributed to SLWT failure due to minimal repair failure of components. By comparing the period by period availability to the period by period point probabilities of failure for Node 1 (Table 5.10) the correspondence between low availability and high failure rate may be seen.
**TABLE 5.11 AVAILABILITY OF END ITEM (SLWT)**

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TABLE 5.12 SUPPORT AREA COST SUMMARY

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5.4.4 Cost of Logistics Policy. Tables 5.12 and 5.13 summarize the period by period costs to operate the population of SLWT's in each environment. A period equivalent cost per environment is also given. As can be seen in the charts, shortage penalties played a significant role in the total costs and the operating cost per unit for the SLWT's operating in both environments. The negative capital cost figures represent salvage values received for SLWT's that failed fatally. While these cost figures, especially the shortage penalty, may not be exact, the relative costs of operation between the two environments serves as an index that tradeoffs may be evaluated against.

5.4.5 Sensitivity Analysis. Sensitivity analysis that might be performed on this case study would involve changing certain parameters in order to make improvements in availability and logistics policy costs. Very high costs are being incurred in each of the two failure environments because of shortage penalties. In this case study, the logistics decision maker could increase availability (and thus reduce shortage costs) by increasing the population size of SLWT's in either or both environments. Availability also could be improved if preventive maintenance policies could be implemented to improve component MTBF's. In the case of the Combat Zone Environment, if the fatal failure rate of SLWT's could be
reduced, availability would improve. Improvements in repair practices could reduce MTTR's and thereby increase the availability of the SLWT's.

Making changes in the procurement policy used could improve cost and availability. If the logistics decision maker has choices in quality of components installed on the SLWT, then better quality components should result in longer MTBF's which would result in better availability. The effects on cost would have to be evaluated.

The model is designed so that the decision maker can make sensitivity analyses involving many different parameters. As the model is set up now, sensitivity analysis will require the manual changing of the desired parameter and then a new run of the model. As described earlier in this thesis, some of these parameters will be under the total control of the logistics decision maker, some of these parameters have upper and/or lower limits within which the decision maker must work, and some of the parameters are set and cannot be changed.

5.4.6 Uses of the Model Output. The uses of model output is limited only by the imagination of the model user. Some of the more obvious uses of the particular output produced for Case Study 1 would include establishing stockable items ordering and stocking policies. The manpower requirements generated by the model could help in
the staffing of repair facilities and will warn of expected busy periods that are approaching, or of expected periods where personnel should be moved to other locations due to lack of work.

Plots of the period point probabilities of failure at each bottom of the tree node may be compared to actual repair data so that the model failure rates may be fine tuned to more closely approximate reality. The plots also show patterns in component failure rates that may lead to requested improvements in performance or to the use of different types of components that exhibit more favorable failure characteristics. Tracking the failure rates of nodes higher in the maintenance tree helps to point out systems of components that create the most failure problems on the SLWT. Paying special attention to preventive maintenance or offering better protection to these systems may prove to be worthwhile.

The availability data is especially crucial to the logistics decision maker. This data tells him whether or not the logistics support being provided is allowing the population of SLWT's to accomplish its designed mission. Various data output by the model may point to the area in which improvements can be made to increase availability. This is discussed in the previous subsection.
The model output could be used as a tool to provide data necessary to guide higher level decision makers. For instance, if the logistician were to demonstrate to the appropriate military personnel that the high fatal failure rate of the SLWT's in the Combat Zone resulted in low availabilities of the SLWT's in the latter stages of the 1 year time period evaluated, it may be possible to gain greater protection against hostile forces. Better protection would, in effect, reduce the fatal failure rate of the SLWT's in the Combat Zone to a more acceptable rate.

The model helps to determine what size of population must be supported and how much it will cost to field and support that population. Thus, the model output can serve as a budgeting aid for capital, as well as, operations budget planners. If extremely expensive populations, such as the SLWT's, are being evaluated, the output of this model could prove invaluable to high level decision makers who must appropriate the funds necessary to field and support such a system.

5.5 CASE STUDY 2.

A scenario for a second case study is described here to better illustrate some of the "what if" gaming capabilities of the model. This particular case study scenario also illustrates the model's value as a long range planning tool.
Assume we are evaluating the same population of SLWT's, operating in the same two failure environments, with the same number of units being assigned to each environment. The effects of minimal repair type failures on SLWT availability is assumed to be negligible. Only the probability of fatal failure will have any real effect on the ability of the two groups of SLWT's to perform their mission.

It is of utmost importance for the logistics planner to have knowledge of the expected ability of the SLWT's in each environment to perform their missions. An established availability must be met. Running the model versus this availability and playing "what if" games with the population size and the procurement policies used, will help the planner meet the availability requirement at an acceptable cost. Once this cost has been established, the planner has the information he needs to put together the budget package and support data that high level decision makers will use in appropriating the money necessary to field the SLWT's.

5.6 CASE STUDY 3.

A scenario for a third case study is described here to illustrate the micro-capabilities of the model. An astute reader may have noticed that in Case Study 1 there is no node assigned to an engine to propel the SLWT. The reason
for this is that the engine has a whole maintenance tree to itself. An entire case study could be built around the particular diesel engine that powers the SLWT, and possibly other Navy vessels.

Assume quality is also an issue in the evaluation of the diesel engine, as there are two manufacturers of diesel engines that are compatible with the SLWT. The engines have virtually identical maintenance trees, but one engine utilizes better quality components, in many cases. The better quality engine carries a higher first cost and higher stockable item costs. On the other hand, the quality engine has higher salvage and book values, and lower repair costs. The quality engine also has longer MTBF's and shorter MTTR's for many of its "bottom of the tree" node components.

The logistician's problem is deciding whether to spend the extra money up front to buy a better engine, or hope that the lesser priced engine will serve adequately without creating extremely high operations and maintenance costs. To evaluate this situation, the model could be run once for each brand of engine with the engines being placed in the same environment, and applying the same repair policy to each engine, i.e. similar components require the same repair level. The availability and logistics policy cost data produced should identify which engine will meet the
necessary requirements for the lowest cost. Remember, also that different quality engines could affect manpower requirements and inventory practices at repair facilities.

When a diesel engine has been selected for use in the SLWT, the engine should be added to the maintenance tree in Case Study 1 as a "bottom of the tree" node. The node should have period by period failure probabilities equal to the Node 1 (End Item) failure probabilities generated by the model in Case Study 3. Use the model in Case Study 3 to evaluate the specific maintenance requirements of the diesel engine and add these requirements to the other SLWT requirements generated by Case Study 1.
6.1 SUMMARY.

It was stated in Chapter I of this thesis that a major weakness of existing maintenance or logistics models was their lack of ability to evaluate nonsteady-state phases of operation of various populations of items. From this problem arose the objective of this research, that being to develop a model that could evaluate the period by period maintenance requirements of repairable item populations over their entire life cycle. This life cycle could include transient, as well as steady-state phases of operation, where period to period failure rates could be distributed in a variety of configurations.

A literature review was conducted that summarized the types of models that had been produced in the logistics or maintenance modeling area. Concepts developed by Frisch [5] were found to be conducive to transient state evaluation of maintenance requirements, and were expanded upon and included in this research.

Chapter III of this thesis developed the concepts and computational methods that formed the basis of this model. Assumptions, decision variables, and other parameters were detailed. The many possible ways in which a logistics
decision maker could use this model were also expounded upon.

The limitations of the model due to limiting assumptions, computing power, and the lack of failure and repair data were discussed in Chapters III and IV. Finally, the model was validated by illustrating its application to a case population of Side Loadable Warping Tugs. The population evaluated was, in many ways, similar to an actual population of SLWT's presently used by the U.S. Navy. This case study demonstrated the spare part demand, inventory level, warehousing demand, availability, repair facility demand, and logistics policy cost outputs produced by the model.

6.2 CONCLUSIONS.

Upon completing this research project, it does appear to be feasible to attempt to produce expected maintenance requirements for transient phases of operation of repairable item populations. The model developed does meet the list of objectives stated in Section 1.2. The two major concepts applied in this model proved to be conducive to the generation of total life cycle maintenance requirements. The multi-stream concept meshes well with the idea of population end items experiencing different maintenance requirements at different stages of their life cycles. The maintenance tree concept recognizes that
different components of an end item can possess very
different rates of failure and mean times to repair, and
provides a structured method of evaluating the maintenance
requirements generated by specific components. Using the
structure of the tree, these specific requirements are
summed to produce end item maintenance requirements.

This model illustrates the value of having one
maintenance model that can produce as many aspects of the
maintenance requirements of a population as possible. By
having spare parts demand, inventory levels, warehousing
demand, availability, repair facility demand, and logistics
policy cost information provided by one run of one model,
the logistics planner has the opportunity to study the
interrelationships among the different maintenance
requirements generated for the population under study.
Taking this idea further could involve tying this model
into a Material Requirements Planning System. The model
would generate data that the MRP system could use in
stocking parts and planning warehouse operations.

One major conclusion of this research is that failure
rate and repair data for either end items or components is
difficult to obtain. As discussed earlier in this thesis,
the sources of such data is limited. It can only be hoped
that this model, and other models, will demonstrate the
value of possessing and utilizing failure and repair data.
Savings and increased success of missions resulting from good logistics planning should outweigh any difficulties involved with establishing data collection systems that track failure and repair data.

The data necessary for good logistics planning does, however in itself, represent a paradox. As was discovered while building this model, not only is a large data input required, but the data multiplies many times over as period by period maintenance requirements are generated. This means that the model is tracking a huge amount of data. This large quantity of data creates two major concerns for the model developer. First, a large computer memory must be provided in order to store the data. Second, the model developer must be very careful in choosing meaningful data to display to the user of the models, in order to avoid information saturation.

The SLWT case study illustrates exactly why it can be crucial to be able to evaluate transient state phases of operation, as well as, steady-state phases of operation. In observing the plots of end item period point probabilities of failure, it can be seen that the SLWT's began to exhibit a sort of steady-state failure pattern only after about five periods of operation (see Figure 5.6). The typical mission length for a population of SLWT's is one to five periods. Therefore, the SLWT's
mission is, in most cases, nearly over before any semblance of steady-state is reached. Furthermore, as evidenced by the period point probabilities of failure for Nodes 107 and 108 (see Figures 5.4 and 5.5), there can be component failure rates driving the end item failure rate that never reach a steady state. Nonsteady-state periods of operation can be evaluated in detail if the period lengths used in the model are of short duration, and if the failure data warrants such detail. Decreasing the period lengths evaluated by the model can produce a discrete approximation of continuous maintenance requirements. Figure 3.2 illustrated this concept.

As is the case with most research, several limiting assumptions were employed in the development of this model. Relieving as many of these assumptions as possible could do nothing but add to the accuracy of the expected maintenance requirements generated by this model. Extensions of the research that might relieve some of the assumptions are described in the next section.

6.3 RECOMMENDATIONS.

The research involved with the development of this model has only scratched the surface of estimating the maintenance requirements of repairable item populations operating under transient conditions. There are many computer related improvements that can be made to improve
the usability and the capabilities of the present model. In addition, research can be extended in many directions to give more depth and therefore more accuracy to expected maintenance requirements produced by transient state models.

Computer related improvements include:
1 - Make improvements to the input and display routines of the model in order to increase the speed with which the user can program the model. Displaying summaries of input data and making all input data easily accessible for change would be the types of improvements called for here.

2 - Increase the speed of model execution. This could be accomplished by compiling the existing program, reprogramming in more efficient computer languages, and/or using a computer with a larger random access memory.

3 - Build scenario generators into the model so that such things as changing costs and demands can be evaluated.

Extensions of this research, in the context of evaluating transient state operation, could take any of the following directions:

1 - Develop methods for evaluating the uncertainty present in failure and repair data.
2 - Refine the methods for calculating the times at which end items fail so as to gain a more exact estimation of the expected repair facility and spare parts demand.

3 - Incorporate the modeling of repair functions into the model, i.e., all of the events that transpire between an end item failure and the time that the end item returns to operation.

4 - Incorporate different methods for establishing inventory levels of spare parts.

5 - Evaluate the effects of redundant components and noncritical failure of components on maintenance requirements.

6 - Evaluate the effects of preventive maintenance on maintenance requirements.

7 - Develop the concept of shortage penalties and the manner in which they should be applied to the evaluation of maintenance requirements. Decision methods for evaluating tradeoffs involving shortage penalties would be of great value to the logistics planner as shortage penalties are generally difficult to quantify.
REFERENCES


25. Phelps, E.S., "Optimal Decision Rules for the Procurement, Repair or Disposal of Spare Parts", RAND Memorandum RS-2920PR, the Rand Corporation, Santa Monica, Cal., 1962.


APPENDIX 1.

Case Study 1
Period by Period Spare Parts
and
Warehouse Summaries
## PERIOD 1 SPAREPARTS AND WAREHOUSE REQUIREMENT SUMMARY

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<th>Node</th>
<th>Part#</th>
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<th>W'house EOQ (cuft)</th>
<th>Total Repair Cost</th>
<th>Level</th>
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Total warehouse requirement repair level 1 = 361.32
Total warehouse requirement repair level 2 = 106.71
Total warehouse requirement repair level 3 = 0.00
## PERIOD 2 SPAREPARTS AND WAREHOUSE REQUIREMENT SUMMARY

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<th>EOQ</th>
<th>Total Repair Cost</th>
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## PERIOD 3 SPAREPARTS AND WAREHOUSE REQUIREMENT SUMMARY

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PERIOD 4 SPAREPARTS AND WAREHOUSE REQUIREMENT SUMMARY

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## PERIOD 5 SPARE PARTS AND WAREHOUSE REQUIREMENT SUMMARY

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## Period 6 Spare Parts and Warehouse Requirement Summary

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## PERIOD 10 SPARE PARTS AND WAREHOUSE REQUIREMENT SUMMARY

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PERIOD 11 SPAREPARTS AND WAREHOUSE REQUIREMENT SUMMARY

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Total warehouse requirement repair level 1 = 298.97
Total warehouse requirement repair level 2 = 124.88
Total warehouse requirement repair level 3 = 25.00
APPENDIX 2.

Program Listing
DEFINITION OF VARIABLES

A$,C$,%$,P$,Q$,V$,VT$,VV$,do loop counter variables
A$ ....inkey string variable
ACOST(e) ....average operation cost per end item
per period in environment e
AMT%(p) ....number end items procured at
procurement p
AVAIL ....sum of environment availabilities
AVAILABILITY(e) ....availability of end items per period
in environment e
AVGMTTR(e) ....MTTR for an end item per period in
environment e
AVGPF(e) ....probability of end item failure per
period in environment e
AVGSTREAM ....average number of end items operating
in a stream during a period
BV(e) ....book value at retirement for an end
item in environment e
C1(e) ....capital costs for end items in
environment e
C2 ....repair costs for end items in
environment e
C3 ....shortage costs for end items in
environment e
C4(e) ....inventory costs for end items in
environment e
C5(e), C6(e), C7(e), C8(e), C10(e) ....present worth
values of costs for environment e
CC ....first cost of an end item
CCH(n) ....holding cost for stockable item on
node n
CCP(n) ....procurement cost for stockable item
on node n
CDF$,CDFP$,CDFP%. ....failure curve file variable
CDF$ ....failure curve number
CDF1X(n), CDF2X(n), CDF3X(n), CDF4X(n), CDF5X(n)
 ....failure curves for node n in
environments 1,2,3,4, or 5
CH ....holding cost for stockable item
CL ....% of days between EOQ orders
CNT1%,CNT2%,CNT3%,CNT4% ....counter variables
CODEX ....repair level for stocking components
CP ....procurement cost for stockable items
CT5, CT5$ ....time parameter used in probability of
failure cumulative distributions
D% ....signal to compute end item
procurement cost if = 1
D2X ....signal if = 1, the component
regenerates during period
DEMAND%(e) ....demand for end items in environment e
signal for chaining to designate spot in program to chain back to all Fn$ variables are print formats variable for binomial availability computation all FILEn$ variables are file names fraction of period until component cumulative probability function regenerates fraction of period during which number of end items in operation exceeds demand for environment e cumulative probability of component failure during period warehouse requirement for stockable items at node n in one time period per period interest rate stockable item name components in initial procurement number of end items placed in stream s of failure environment in which stream s operates signal variable for procurement = A infinite procurement = B procure to upper limit summing variables used to calculate union of node failure probabilities array subscripts used to calculate union of node failure probabilities lead time for stockable item on node n length of modal run Eoq minimum cost procurement level stockable item lead time length of time period number of days in a time period holding arrays used to calculate union of node failure probabilities components MTBF for component n in environments 1,2,3,4, or 5 mean time to repair for components MTTR for component n in environments 1,2,3,4, or 5 weighted sum of component MTTR's in stream s failure probability for component n node name for node n name for stockable item on node n name of environment e number of failure environments number of repair levels previous period failure probability for node n failure probability for node n #failure probability for stockable item on node n number of repair levels for node n number of end items in period equal to MTTR procurement $ (for end items) number of failure environments present worth conversion factor or period cost conversion factor and item procurement cost
"MAIN" PROGRAM LISTING

This section of the program is the driver for the remainder of the model and represents the computational basis for the model developed.

CHAIN TO THE INTRODUCTORY PROGRAM

MAIN PROGRAM LISTING

'k'
..... = 2 cease procurement at upper limit
'MH(r)'..... = 1 maintain upper population limit
'H(r)'..... = 1 period warehouse requirement at repair level r
'XX,XXX,YY,YYY'...array subscripts for calculating union of failure probabilities

Note: The majority of the variables are initialized in the input program, INPUT1. All arrays are dimensioned in INPUT1.

F% = 0: NS% = 1: D% = 0: SIG% = 0: PLEN% = 0: PRC = 0

If an existing population is being evaluated,

CHAIN TO PROGRAM TO ALLOW USER TO SPLIT THE END ITEMS INTO STREAMS

If there is more than one failure environment and if an initial procurement has been made,

CHAIN TO PROGRAM TO SPLIT END ITEMS INTO STREAMS

Initialize variables based on initial procurement amount

Begin loop to evaluate period by period requirements

T% = 1
CNT% = 0
FOR N% = 1 TO 5
C4(N%) = 0: MP(N%) = 0

END OF PROGRAM
BEGIN LOOP TO EVALUATE STREAM BY STREAM REQUIREMENTS

FOR C% = 1 TO NS%-1
IF ST%(C%) = 0 THEN
   TT% = T% - TTIME%(C%)
   O%(C%) = IP%(C%) - ST%(C%)
   IF TT% >= RRA%(C%) + 1 THEN
      FILE$ = "0" + STR$(C%)
      FOR N% = 1 TO 126
         NODE(N%) = 0: NODEP(N%) = 0
      NEXT N%
   END IF
   LOAD ENVIRONMENT SPECIFIC NODE DATA INTO ARRAYS
   ON KKEY%(C%) GOSUB 5360,5520,5680,5840,6000
   HTTRSUM = 0: CNT4 = 0
   BEGIN LOOP TO EVALUATE NODE BY NODE FAILURE PROBABILITIES
   FOR N% = 1 TO 126
      IF NODEP(N%) = 0 THEN
         MTBF = MTBF%(N%): A% = NODEP(N%)
         CDF% = CDF%(N%)
         FILE$ = "0" + STR$(KKEY%(C%)) + STR$(N%)
         IF CDF% = 6 THEN GOTO 3520
         IF (2*MTBF) < 1 THEN GOSUB 7320
         IF TT% = 1 AND TT% <= (2*MTBF) THEN CT5 = 1
         GOTO 3450
      OPEN "r",#2,FILE3$,4 AS NODE$,
         GET #2,TT%: NODEP(N%) = CVS(NODE$) CLOSE #2
      FR2 = (2*MTBF) - CT5 + 1
      GOTO 3620
   NEXT N%
   FOR N% = 1 TO 126
      IF NODEP(N%) = 0 THEN
         SUMA = 0
         IF D2% = 1 THEN NODEP(N%) = (FR2*(1-SUMA)) + ((1-FR2)*FT)
         GOTO 3670
      SUMA = FT
      NODEP(N%) = FT - SUMA
      GOTO 3670
      D2% = 0
      gosub to sum weighted node HTTR's
      GOSUB 7090
   NEXT N%
   IF CDF% = 6 THEN
      SUMA = FT
      IF CT5 = 0 THEN SUMA = 0
      OPEN "r",#2,FILE3$,12
      FIELD "2,4 AS NODE$, 4 AS SUMA$, 4 AS CT5$
   END IF
   GOTO 3670
GET $2,A% 
LSET NODE$ = MKS$(NODE(A%)) 
LSET SUMA$ = MKS$(SUMA) 
LSET CT5$ = MKS$(CT5)
PUT $2,A% 
CLOSE 2
NEXT N% 

GOSUB TO COMPUTE END ITEM MTTR FOR STREAM

GOSUB 7180

GOSUB TO COMPUE #UNITS LEFT OPERATING IN STREAM

GOSUB 5010
GOSUB TO CALCULATE NODE BY NODE FAILURE PROBABILITIES FOR MAINTENANCE TREE FOR STREAM

GOSUB 7460

IF SPHA% = 3 THEN 4030
CNT1% = CNT1% + 1

GOSUB TO COMPUTE STREAM SPAREPARTS DEMAND

ON SPHA% GOSUB 9690,10100 GOTO 4180

IF STREAM RETIRED OR ALL UNITS FAILED FATALY, PRINT MESSAGE

IF UP% = 1 THEN 4100
LPRINT "All remaining units of stream("
"have been retired."); GOTO 4210

LPRINT "All remaining units of stream("
"have been retired."); GOTO 4210

IF UP% = 1 THEN 4119
LPRINT "Time Period": T%

LPRINT "Units Initially"

LPRINT "Procured": IP%(CHR%)

LPRINT "Stream has been Retired": GOTO 4210

CLS: COLOR 2,0: LOCATE 1,40

LOCATE 2,40: PRINT "Stream ": C%

LOCATE 3,40: PRINT "Units Initially"

LOCATE 4,40: PRINT "Procured": IP%(CHR%)

LOCATE 5,40: PRINT "Stream has been Retired"

COLOR 3,0: LOCATE 20,50

PRINT "Press any key to continue."

A$ = INKEY$: IF A$ = "": GOTO 4200

NEXT C% 

GOSUB TO COMPUTE PERIOD SPAREPARTS AND WAREHOUSE REQUIREMENTS

GOSUB 8820

IF SPHA% = 3 THEN 4320
ON SPHA% GOSUB 9740,10240

GOSUB TO CALCULATE AVAILABILITY

GOSUB 8820

IF T% = LMR% THEN 4830

IF PROCUREMENT POLICY IS BEING GENERATED GOTO 2310 OTHERWISE USER HAS OPPORTUNITY
TO INPUT A PROCUREMENT AMOUNT OF END ITEMS

AT THIS POINT

IF PL% <> 9 THEN 6690
COLOR 3,0: LOCATE 17,30
PRINT "End of period, do you wish to "
"make a procurement?"
COLOR 2,0: LOCATE 18,30
INPUT "Enter yes or no >",A$
IF A$ = "no" THEN 4830

GOSUB FOR MANUAL INPUT OF PROCUREMENT AMOUNT

GOSUB 6690
IF NO.ENVIR% = 1 THEN 4590
CHAIN TO PROGRAM TO DIVIDE PROCUREMENT
INTO STREAMS

F% = 1: CHAIN "DIVIDE", 400, ALL
KKEY%(NS%) = 1: TTIME%(NS%) = T%
ST%(NS%) = IP%(NS%): RRA(NS%) = RA(1)
IF IP%(NS%) > 0 THEN NS% = NS% + 1: DX=1
GOTO 4820

IF CNT3% INDICATES THAT IT IS TIME TO MAKE A
PROCUREMENT OF END ITEMS THEN GOSUB TO THE
ROUTINE THAT WILL GENERATE PROCUREMENT AMOUNT

CNT3% = CNT3% + 1
IF CNT3% < NO.P.PERC% THEN 4850
ON PL% GOSUB 6090,6090,6230,6230,6330, 6330,6510,6510

CHAIN TO PROGRAM TO DIVIDE PROCUREMENT
INTO STREAMS

F% = 2: CHAIN "DIVIDE", 400, ALL
KKEY%(NS%) = 1: TTIME%(NS%) = T%:
ST%(NS%) = IP%(NS%): RRA(NS%) = RA(1)
IF IP%(NS%) > 0 THEN NS% = NS% + 1: DX=1
CNT3% = 0
IF T% = LMR% THEN 4900
T% = T% + 1: GOTO 2990

GOSUB TO CALCULATE PERIOD EQUIVALENT COST FOR
MODEL RUN

GOSUB 12710
IF UP% = 0 THEN 4940
COLOR 3,0: LOCATE 20,50
PRINT "Press any key to continue."
A$ = INKEY$: IF A$ = "" THEN 4930

CHAIN TO PROGRAM TO GIVE PRINTER LISTING OF
MODEL RUN RESULTS

CHAIN "PRINTOUT", 36000!, ALL
END OF MAIN PROGRAM

SUBROUTINE TO CALCULATE NUMBER OF UNITS THAT
FAIL FATALLY DURING PERIOD
SUBROUTINES TO SAVE NODE BY NODE
INPUT DATA BY FAILURE ENVIRONMENT
THESE SUBROUTINES ARE ALSO USED TO LOAD THE
NODE BY NODE DATA BACK INTO THE PROPER ARRAY
SO FAILURE PROBABILITIES MAY BE CALCULATED

save failure environment #1 input

load failure environment #1 data into arrays

FOR PX = 1 TO 126
MTBF1(PX) = MTBF; NODE1(PX) = AZ
CDF1(PX) = CDFX; MTR1(PX) = MTR
NEXT PX
RETURN

save failure environment #2 input

load failure environment #2 data into arrays

FOR PX = 1 TO 126
MTBF2(PX) = MTBF; NODE2(PX) = AZ
CDF2(PX) = CDFX; MTR2(PX) = MTR
NEXT PX
RETURN

save failure environment #3 input

load failure environment #3 data into arrays

FOR PX = 1 TO 126
MTBF3(PX) = MTBF; NODE3(PX) = AZ
CDF3(PX) = CDFX; MTR3(PX) = MTR
NEXT PX
RETURN

save failure environment #4 input
5800 'load failure environment #4 data into arrays
5810 NODE4(AX) = A
5820 CDF4(AX) = CDF;
5830 RETURN
5840 'load failure environment #5 data into arrays
5850 NODE5(AX) = A
5860 CDF5(AX) = CDF;
5870 RETURN
5880 FOR P0 = 1 TO 126
5890 MTBF(P0) = MTBF(AX) = NODE4(P0) = NODE5(P0)
5900 CDF(P0) = CDF4(P0) = MTTR(P0) = MTTR4(P0)
5910 NEXT P0
5920 RETURN
5930 'save failure environment #5 input
5940 RETURN
5950 'SUBROUTINE TO PERFORM UNIFORM PROCUREMENT
5960 'SUBROUTINE TO PERFORM BLOCK PROCUREMENT
5970 MTBF5(AX) = MTBF: NODE5(AX) = A
5980 CDF5(AX) = CDF: MTTR5(AX) = MTTR
5990 RETURN
6000 'load failure environment #5 data into arrays
6010 FOR P0 = 1 TO 126
6020 MTBF5(P0) = MTBF5(AX) = NODE5(P0) = NODE5(P0)
6030 CDF5(P0) = CDF5(P0) = MTTR5(P0) = MTTR5(P0)
6040 NEXT P0
6050 RETURN
6060 IF L$ = "A" THEN IP%(NS%) = UPA%; RETURN
6070 IF SIG% = 1 THEN RETURN
6080 FOR P0 = 1 TO NS%-1
6090 SUM% = SUM% + ST%(P0)
6100 NEXT P0
6110 IF SUM% + UPA% >= UP.LIMIT% THEN 6210
6120 IF W% = 2 THEN SIG% = 1
6130 IF SUM% + UPA% >= UP.LIMIT% - SUM% THEN RETURN
6140 'SUBROUTINE TO PERFORM INCREASING PROCUREMENT
6150 'SUBROUTINE TO PERFORM UNIFORM PROCUREMENT
6160 'SUBROUTINE TO PERFORM BLOCK PROCUREMENT
6170 'SUBROUTINE TO PERFORM INCREASING PROCUREMENT
6180 'SUBROUTINE TO PERFORM UNIFORM PROCUREMENT
6190 'SUBROUTINE TO PERFORM BLOCK PROCUREMENT
6200 'SUBROUTINE TO PERFORM INCREASING PROCUREMENT
6210 'SUBROUTINE TO PERFORM UNIFORM PROCUREMENT
6220 'SUBROUTINE TO PERFORM BLOCK PROCUREMENT
6230 'SUBROUTINE TO PERFORM INCREASING PROCUREMENT
6240 'SUBROUTINE TO PERFORM UNIFORM PROCUREMENT
6250 'SUBROUTINE TO PERFORM BLOCK PROCUREMENT
6260 'SUBROUTINE TO PERFORM INCREASING PROCUREMENT
6270 'SUBROUTINE TO PERFORM UNIFORM PROCUREMENT
6280 'SUBROUTINE TO PERFORM BLOCK PROCUREMENT
6290 'SUBROUTINE TO PERFORM INCREASING PROCUREMENT
6300 'SUBROUTINE TO PERFORM UNIFORM PROCUREMENT
6310 'SUBROUTINE TO PERFORM BLOCK PROCUREMENT
6320 'SUBROUTINE TO PERFORM INCREASING PROCUREMENT
6330 'SUBROUTINE TO PERFORM UNIFORM PROCUREMENT
6340 'SUBROUTINE TO PERFORM BLOCK PROCUREMENT
6350 'SUBROUTINE TO PERFORM INCREASING PROCUREMENT
6360 'SUBROUTINE TO PERFORM UNIFORM PROCUREMENT
6370 'SUBROUTINE TO PERFORM BLOCK PROCUREMENT
6380 'SUBROUTINE TO PERFORM INCREASING PROCUREMENT
6390 'SUBROUTINE TO PERFORM UNIFORM PROCUREMENT
6400 'SUBROUTINE TO PERFORM BLOCK PROCUREMENT
6410 'SUBROUTINE TO PERFORM INCREASING PROCUREMENT
6420 'SUBROUTINE TO PERFORM UNIFORM PROCUREMENT
6430 'SUBROUTINE TO PERFORM BLOCK PROCUREMENT
6440 'SUBROUTINE TO PERFORM INCREASING PROCUREMENT
6450 'SUBROUTINE TO PERFORM UNIFORM PROCUREMENT
6460 'SUBROUTINE TO PERFORM BLOCK PROCUREMENT
6470 'SUBROUTINE TO PERFORM INCREASING PROCUREMENT
6480 'SUBROUTINE TO PERFORM UNIFORM PROCUREMENT
6490 'SUBROUTINE TO PERFORM BLOCK PROCUREMENT
6500 'SUBROUTINE TO PERFORM INCREASING PROCUREMENT
6510 'SUBROUTINE TO PERFORM UNIFORM PROCUREMENT
SUBROUTINE TO PERFORM DECREASING PROCUREMENT

SUBROUTINE TO TAKE MANUAL PROCUREMENT INPUT

SUBROUTINES TO CALCULATE CUMULATIVE FAILURE PROBABILITIES FOR BOTTOM OF THE TREE NODES

failure curve 1: uniform distribution

failure curve 2: exponential distribution

failure curve 3: increasing exponential

failure curve 4: normal distribution

failure curve 5: bathtub distribution

SUBROUTINE TO SUM THE WEIGHTED NODE MTTR'S

SUBROUTINE TO COMPUTE MTTR FOR STREAM
SUBROUTINE USED TO CALCULATE NODE FAILURE PROBABILITY IF THE EXPECTED LIFE OF THE COMPONENT REPRESENTED BY THAT NODE (2*MTBF) IS LESS THAN ONE PERIOD.

SUBROUTINES TO CALCULATE NODE FAILURE PROBABILITIES FROM THE BOTTOM TO THE TOP OF THE MAINTENANCE TREE.

print stream information on output screen.

driver for node summing subroutine.
7870 GOSUB 8500
7880 IF NODE(1) = 0 THEN NODE(1) = LLLL
7890 print node failure probability
7910 IF UP% = 1 THEN 7930
7920 LPRINT USING F9$;"node(\%1) = \";NODE(1)
7930 GOTO 7950
7950 COLOR 2,0: LOCATE P% - 6 + RRR, 1
7960 PRINT USING F9$;"node(\%1) = \";NODE(1)
7970 XX:=005: XXX:=000+5
7980 NEXT P%
7990 RRR = RRR + 1: L1 = 0: L2 = 0: L3 = 0: L4 = 0
8000 FOR Q% = VY TO YYY
8010 MIQ%1 = NODEIQ%
8020 NEXT Q%
8030 IF CNT2% = 5 THEN 8140
8040 gosub to evaluate union of node probabilities
8050 GOSUB 8500
8060 IF NODE(1) = 0 THEN NODE(1) = LLLL
8070 print node failure probability
8080 RR = RR + 6: LOCATE RR, 26
8090 IF UP% = 1 THEN 8150
8100 LPRINT USING F9$;"node(\%1) = \";NODE(1)
8110 GOTO 8130
8120 YY=YY+5:YYY=YYY+5
8130 NEXT W.
8140 RR = RR + 6: LOCATE RR, 26
8150 IF UP% = 1 THEN 8190
8160 LPRINT USING F9$;"node(\%1) = \";NODE(1)
8170 GOTO 8140
8180 L1 = 0: L2 = 0: L3 = 0: L4 = 0: L5 = 1: LL = 1
8190 LLL = 5: CNT2% = 0: M(6) = NODE(6): LL = 2: LLL = 6
8200 FOR Q% = 2 TO 5
8210 MIQ%1 = NODEIQ%
8220 NEXT Q%
8230 gosub to evaluate union of node probabilities
8240 GOSUB 8500
8250 IF NODE(1) = 0 THEN NODE(1) = LLLL
8260 gosub to evaluate probability of end item failure without regard to fatal failure (for use in availability subroutine)
8270 GOSUB 8710
8280 print node 1 probability of failure (includes fatal failure)
8290 subroutine to evaluate the union of node failure probabilities
8300 IF UP% = 1 THEN 8410
8310 GOTO 8440
8320 LOCATE 22,40: PRINT "press any key to continue";
8330 RETURN
8340 A$=INKEY$: IF A$ = "" THEN 8430
8350 8410 IF UP% = 1 THEN 8440
8420 GOTO 8440
8430 LOCATE 22,40: PRINT "press any key to continue"
8440 RETURN
8450 subroutine to evaluate the union of node failure probabilities
8500 FOR Q% = LL TO L LL
8510 L1 = L1 + MIQ%
8520 FOR W% = Q% TO LL-1
8530  \[ L_z = L_z + (M(z) \times M(v^z+1)) \]
8540  \[ \text{NEXT } v_z \]
8550  \[ M(z) = M(z) \]
8560  \[ \text{IF } M(z) = 0 \text{ THEN } M(z) = 1; \]
8570  \[ Z_z = Z_z + 1 \]
8580  \[ \text{NEXT } Z_z \]
8590  \[ \text{IF } Z_z > 0 \text{ THEN } L_5 = 0 \]
8600  \[ Z_z = 0 \]
8610  \[ \text{IF } CNT2_z > 3 \text{ THEN } \text{RETURN} \]
8620  \[ L_3 = M(\text{LL}) \times M(\text{LL}+2) \times M(\text{LL}+3) \times M(\text{LL}+4) \]
8630  \[ L_3 = L_3 + M(\text{LL}) \times M(\text{LL}+2) \times M(\text{LL}+3) \times M(\text{LL}+4) \]
8640  \[ M(\text{LL}) \times M(\text{LL}+2) \times M(\text{LL}+3) \times M(\text{LL}+4) \]
8650  \[ L_3 = L_3 + M(\text{LL}+3) \times M(\text{LL}+4) \times M(\text{LL}+1) \times M(\text{LL}+2) \]
8660  \[ L_4 = M(\text{LL}) \times M(\text{LL}+1) \times M(\text{LL}+2) \times M(\text{LL}+3) \times M(\text{LL}+4) \]
8670  \[ L_4 = L_4 + M(\text{LL}+2) \times M(\text{LL}+3) \times M(\text{LL}+4) \]
8680  \[ L_4 = L_4 + M(\text{LL}) \times M(\text{LL}+1) \times M(\text{LL}+3) \times M(\text{LL}+4) \]
8690  \[ L_4 = L_4 + M(\text{LL}) \times M(\text{LL}+1) \times M(\text{LL}+3) \times M(\text{LL}+4) \]
8700  \[ \text{RETURN} \]
8710  \[ \text{subroutine to subtract probability of fatal failure from node } 1 \text{ probability of failure} \]
8720  \[ \text{failure from node } 1 \text{ probability of failure} \]
8730  \[ \text{.................................................................} \]
8740  \[ \text{.................................................................} \]
8750  \[ \text{.................................................................} \]
8760  \[ L_1 = (\text{NODE(2)} + \text{NODE(3)} + \text{NODE(4)} + \text{NODE(5)}) \times \text{NODE(6)} \]
8770  \[ L_2 = ((\text{NODE(3)} + \text{NODE(4)} + \text{NODE(5)}) \times \text{NODE(2)}) \]
8780  \[ L_3 = ((\text{NODE(4)} + \text{NODE(5)}) \times \text{NODE(2)} + \text{NODE(3)}) \]
8790  \[ L_4 = \text{NODE(2)} \times \text{NODE(3)} \times \text{NODE(4)} \times \text{NODE(5)} \times \text{NODE(6)} \]
8800  \[ \text{NODIC}_z = \text{NODE(1)} - \text{NODE(6)} - L_1 - L_2 - L_3 - L_4 \]
8810  \[ \text{RETURN} \]
8820  \[ \text{SUBROUTINE TO CALCULATE AVAILABILITY} \]
8830  \[ \text{.................................................................} \]
8840  \[ \text{.................................................................} \]
8850  \[ \text{CLS: COLOR 2,0,8: LOCATE 12,30} \]
8860  \[ \text{PRINT "one moment please"} \]
8870  \[ \text{FOR } N_z = 1 \text{ TO } S \]
8880  \[ \text{SUMFIN}_z = 0; \text{SUMSTREAM}_z = 0; \text{SMTTRIN}_z = 0 \]
8890  \[ \text{SUMSP2}_z = 0; \text{SUMSP}_z = 0 \]
8900  \[ \text{AVAILABILITY}_z = 0 \]
8910  \[ \text{NEXT } N_z \]
8920  \[ \text{FOR } N_z = 1 \text{ TO } N_z-1 \]
8930  \[ \text{SUMSP}_z = \text{SUMSP}_z + \text{SP}_z; \]
8940  \[ \text{SUMSP2}_z = \text{SUMSP2}_z + \text{SP2}_z; \]
8950  \[ \text{SUMFIN}_z = \text{SUMFIN}_z + \text{FIN}_z; \]
8960  \[ \text{SUMSP}_z = \text{SUMSP}_z + \text{SP}_z; \]
8970  \[ \text{SUMSP2}_z = \text{SUMSP2}_z + \text{SP2}_z; \]
8980  \[ \text{SUMFIN}_z = \text{SUMFIN}_z + \text{FIN}_z; \]
8990  \[ \text{SUMSP}_z = \text{SUMSP}_z + \text{SP}_z; \]
9000  \[ \text{SUMSP2}_z = \text{SUMSP2}_z + \text{SP2}_z; \]
9010  \[ \text{NEXT } N_z \]
9020  \[ \text{SUM} = 0; \text{AVAIL} = 0 \]
9030  \[ \text{FOR } N_z = 1 \text{ TO NO.ENVIR} \]
9040  \[ \text{IF } \text{SUMSTREAM}_z = 0 \text{ THEN } \text{AVAILABILITY}_z = 0; \]
9050  \[ \text{GOTO 9290} \]
9060  \[ \text{AVGFIN}_z = \text{SUMFIN}_z / \text{SUMSP}_z; \]
9070  \[ \text{AVGSP}_z = \text{SUMSP}_z / \text{SUMSTREAM}_z; \]
9080  \[ \text{AVGFIN}_z = \text{AVGFIN}_z / \text{AVGSP}_z; \]
9090  \[ \text{IF } \text{SUMSP}_z < \text{DEMAND}_z \text{ THEN } 9240 \]
9100  \[ \text{IF } \text{SUMSP2}_z = \text{DEMAND}_z \text{ THEN } 9120 \]
9110  \[ \text{SUMFIN}_z = \text{SUMSP2}_z + \text{DEMAND}_z \]
9120  \[ \text{SUMFIN}_z = 0 \]
9130  \[ \text{VTZ} = \text{INT(SUMSTREAM}_z - \text{DEMAND}_z); \]
9140  \[ \text{FOR } P_z = 0 \text{ TO VTZ} \]
9150  \[ \text{FAC} = 1 \]
9160  \[ \text{IF } P_z = 0 \text{ THEN } 9200 \]
FOR Q% = 1 TO P%
  FAC = FAC * ((CINT(SUMSTREAM(N%)) - Q% + 1) / (P% - Q% + 1) * P(N%))
NEXT Q%

SUMBINOM = SUMBINOM + (FAC) * 
  (1-P(N%)) * (CINT(SUMSTREAM(N%)) - P%)
NEXT P%

AVAILABILITY(N%) = SUMBINOM
IF SUMSP2%(N%) >= DEMAND%(N%) THEN 9270
IF SUMSP%(N%) < DEMAND%(N%) THEN
  AVAILABILITY%(N%) = 0: GOTO 9270
IF SUMSP%(N%) = DEMAND%(N%) THEN
  AVAILABILITY%(N%) = (1-P(N%)) * (SUMSP%(N%) - IP%)
  NEXT Q%
SUMBINOM = SUMBINOM + IFAC(I) * IP%(N%) - SUMSP%(N%)
AVAILABILITY%(J) = SUMBINOM
  IF SUMSP%(N%) >= OEMAN0%(N%) THEN
    IF SUMSP%(N%) < OEMAN0%(N%) THEN
      AVAILABILITY%(J) = 0: GOTO 9270
    IF SUMSP%(N%) = OEMAN0%(N%) THEN
      AVAILABILITY%(J) = IP%(N%) * SUMSP%(N%) / IP%(N%)
    NEXT Q%
SUH = SUH + SUHSTREAM%(N%)
AVAIL = AVAIL + IAVAILABILITY%(N%)
  NEXT N%

GOTO 9540
CLSA: COLOR 3,0,8
SUBROUTINE TO PRODUCE PERIOD SUMMARY OF SPAREPARTS AND WAREHOUSE REQUIREMENTS

IF UP% = 1 THEN 9790
LPRINT "PERIOD "JTXJ" SPAREPARTS AND WAREHOUSE" "REQUIREMENT SUMMARY"
LPRINT "Spareparts Warehouse Repair"
LPRINT "Node Stockable Item Part#"
"Requirements Requirements Level"
LPRINT: LN% = 0
GOTO 9850
COLOR 3,0: LOCATE 22,50
PRINT "Press any key to continue"
A$=INKEY$: IF A$ = "" THEN 9790
RETURN

SUBROUTINE TO CALCULATE STREAM SPAREPARTS DEMAND IF EOQ CALCULATIONS ARE CALLED FOR
GOSUB 10640
IF UP% = 0 THEN 10140
COLOR 3,0: LOCATE 22,50
PRINT "Press any Key to continue"
A$=INKEY$: IF A$ = "" THEN 10130
RETURN

SUBROUTINE TO PRODUCE PERIOD SUMMARY OF SPAREPARTS AND WAREHOUSE REQUIREMENTS INCLUDING EOQ
GOSUB 13380
IF UP% = 1 THEN 10265
LPRINT "PERIOD "JTXJ" SPAREPARTS AND WAREHOUSE" "REQUIREMENT SUMMARY"
LPRINT "Stockable Part Demand W'house Point Proc."
10258 LPRINT "Node Item" "EOQ Total Repair"
10259 LPRINT " (cu ft) (days) Level" "Cost Level"

10261 LPRINT: LN% = 0
10262 GOTO 10260
10265 CLS: COLOR 3,0
10270 PRINT "PERIOD ";T%J" SPAREPARTS AND WAREHOUSE" "REQUIREMENT SUMMARY"

10280 PRINT
10290 PRINT "Stockable Part# Demand M'house Point Proc." "EOQ Total Repair"
10310 PRINT "Node Item" "EOQ Total Repair"
10320 PRINT " (cu ft) (days) Level" "Cost Level"

10330 PRINT: LN% = 0
10340 •
10360 •
10380 •
10400 •
10420 •
10440 •
10460 •
10480 •
10500 •
10520 •
10540 •
10560 •
10580 •
10600 •
10620 •
10640 •
10660 •
10680 •
10700 •
10720 •
10740 •
10760 •
10780 •
10800 •
OPEN "i", #1, FILE4$; VV% = 1
10800 IF EOF(#1) THEN 11080
10810 OPEN "o", #2, FILE5$; VV% = 1
10820 ON SPHA% GOTO 10830,10840,10850
10830 INPUT #1, I$, PN$, QY, SR%, PR: GOTO 10860
10840 INPUT #1, I$, PN$, QY, SR%, PR, CP, CH, LT: GOTO 10860
10850 INPUT #1, I$, PN$, QY, SR%, PR, CODE%, IAP%, CP, CH, SC
10860 NNAME$(VV%) = I$: PPN$(VV%) = PN$: SSC(VV%) = SC
10870 CCP(VV%) = CP: CCH(VV%) = CH: LLT(VV%) = LT
10880 PRR(VV%) = PR: IIAP%(VV%) = IAP%
10890 IF DT%(VV%) = SR
10900 OPEN "o", #2, FILE5$: Q% = 1 IF EOF(#2) THEN 11060
10910 ON SPHA% GOTO 11080, 11090, 11100
10920 IF LN% < 13 THEN 11040
10930 IF UP% = 0 THEN 11060
10940 PRINT "press any key to view remainder of"
10950 "Spareparts and Warehouse Requirements"
10960 A$ = INKEY$: IF A$ = "" THEN 10950
10970 'print stream spareparts and warehouse demand
10980 '
10990 IF UP% = 1 THEN 11000
11000 USING F2$, N%$1V%): JJ$JPN$JSPR%1VV%JRL%1V%l GOTO 11060
11010 CLS: LN% = 0: LOCATE 3,1
11020 PRINT "Stockable Part#"
11030 PRINT "Quantity Item Repair Level"
11040 PRINT USING F2$, N%$1V%): JJ$JPN$JSPR%1VV%JRL%1V%l
11050 LN% = LN% + 1
11060 IF CNT% <> 1 THEN 11240
11070 OPEN "o", #2, FILE5$
11080 FOR Q% = 1 TO VV% - 1
11090 IF CNT% <> 1 THEN 11240
11100 OPEN "o", #2, FILE5$
11110 FOR Q% = 1 TO VV% - 1
11120 I$ = NNAME$(Q%): PPSR% = SPR%(Q%): PR = PPR(Q%)
11130 SR = FT3(Q%): PN$ = PPSR$(Q%)
11140 CP = CCP(Q%): CH = CCH(Q%): LT = LLT(Q%)
11150 SC = SSC(Q%): IAP% = IIAP(Q%)
11160 ON SPHA% GOTO 11170,11180,11200
11170 PRINT#2, I$: I$, PN$, PPSR%, SR: GOTO 11210
11180 PRINT#2, I$: I$, PN$, PPSR%, PR, IAP%, CP, CH, LT
11190 GOTO 11210
11200 PRINT#2, I$: I$, CP, CH, SC: CODE%
11210 NEXT Q%
11220 CLOSE 2
11230 GOTO 11510
11240 OPEN "i", #2, FILE5$: Q% = 1
11250 IF EOF(2) THEN 11360
11260 ON SPHA% GOTO 11270,11280,11300
11270 INPUT I$, I$, PN$, PPSR%, SR: GOTO 11310
11280 INPUT I$, I$, PN$, PPSR%, SR, PR, IAP%, CP, CH, LT
11290 GOTO 11510
11300 INPUT I$, I$, PN$, PPSR%, SR, PR, IAP%, CP, CH, SC: CODE%
11310 NNAME$(Q%$) = I$: PPSR%(Q%) = SPR%(Q%); LLT(Q%) = LT
11320 FT3(Q%) = SR: PPR(Q%) = PR: SSC(Q%) = SC
11330 CCP(Q%) = CP: CCH(Q%) = CH: PPN$(Q%) = PN$
11340 IIAP%(Q%) = IAP%
11350 Q% = Q% + 1: GOTO 11250
11360 CLOSE 2
11370 OPEN "o", #2, FILE5$
11380 FOR VT% = 1 TO Q% - 1
11390 I$ = NNAME$(VT%): PPSR% = PPSR%(VT%): SPR%(VT%)
11400 PR = PPR(VT%): PN$ = PPN$(VT%)
11410 IAP% = IIAP%(VT%): SR = FT3(VT%)
SUBROUTINE FOR SUMMING AND PRINTING PERIOD

SUMMARY OF INVENTORY REQUIREMENTS

FOR VV% = 1 TO 126
IF VV% = 6 THEN
    IF NODE1%1VY%J = 0 THEN
        FILES$ = "sums" + STR$1VY%J
        FILE6$ = "ssums" + STR$1VY%J
        OPEN "i", #1, FILES$:
        VT% = 1
        IF EOFllJ THEN
            ON SPHA% GOTO 11660,11670
        INPUT #1, I$,PN$,PSPR%,SR: GOTO 11700
        INPUT #1, I$,PN$,PSPR%,SR,PR,IAP%,CP,CH,LT
        GOTO 11700
        INPUT #1, I$,PN$,PSPR%,SR,PR,IAP%,CP,CH,SC,CODE%
        SPR%1VT%J = PSPR%: FT31VT%J = SR
        NNAME$1VT%J = I$:
        CCHIVT%J = CH:
        LLTIVT%J = LT
        IAP%1VT%J = IAP%:
        CCPIVT%J = CP:
        SSCIVT%J = SC
        IF SPHA% = 2 THEN GOSUB 10500
        RLH% = RL%(VY%)
        IF SPHA% = 1 THEN
            FT31VT/.J = FT31VT%J * SPR%1VT%J
            RLH% = RLH% + FT31VT%J
        IF LN. < 13 THEN 11910
        IF UP% = 0 THEN 11820
        CLS: LN% = 0
        IF UP% = 1 THEN 11840
        LPRINT "Spareparts Warehouse Repair"
        LPRINT "Node Stockable Item Part#"
        GOTO 11860
        PRINT "Spareparts Warehouse Repair"
        PRINT "Node Stockable Item Part#"
        PRINT "Requirements Requirements Level"
        GOTO 11850
        PRINT "Order Opt." "Stockable Part# Demand"
        PRINT "House Point Proc. EOQ Total Repair"
        LPRINT "Node Item" "(cuft) (days) Level Cost Level"
        GOTO 11877
        PRINT "Order Opt."
        PRINT "House Point Proc. EOQ Total Repair"
        LPRINT "Node Item" "(cuft) (days) Level Cost Level"
        ON SPHA% GOTO 11920,11950,11990
        COLOR 2,0
        IF UP% = 1 THEN 11930
        LPRINT USING F6$;NHS1(VV%);I$;PN$;PSPR%;FT31VT%J;RLH%
        GOTO 11940
        PRINT USING F6$;NHS1(VV%);I$;PN$;PSPR%;FT31VT%J;RLH%
        LN% = LN% + 1: GOTO 11990
        COLOR 2,0
IF UP\% = 1 THEN 11960
LPRINT USING F3\$; NN\$(VV\$)\$; PN\$; P$PR\%; F3\$(VT\$); OED\$; LPRIME; GPRIME; TCPRIME; RL\%
GOTO 11970
PRINT USING F3\$; NN\$(VV\$)\$; PN\$; P$PR\%; F3\$(VT\$); OED\$; LPRIME; GPRIME; TCPRIME; RL\%
LN\% = LN\% + 1
GOSUB 13500
VT\% = VT\% + 1: GOTO 11640
CLOSE 1
NEXT VV\%
RETURN

' SUBROUTINE TO PRINT TOTAL PERIOD WAREHOUSE
' REQUIREMENT BY REPAIR LEVEL

' SUBROUTINE TO PRINT TOTAL PERIOD WAREHOUSE
' REQUIREMENT BY REPAIR LEVEL

' SUBROUTINE TO CALCULATE AND PRINT PERIOD
' BY PERIOD COST OF LOGISTICS POLICY

IF R\% < NS\%-1 THEN D\% = 1
FOR N\% = 1 TO NS\%-1
IF SP\%(N\%) = 0 THEN 12490
TT\% = T\% - TTIME\%(N\%)
SVC = (SP\%(N\%)-SP\%(N\%)) * SV
IF SVC < 0 THEN SVC = 0
IF N\% > RL\% THEN 12340
C1\%(KEY\%(N\%)) = C1\%(KEY\%(N\%)) - SVC: GOTO 12350
C3\%(KEY\%(N\%)) = C3\%(KEY\%(N\%)) + (IP\%(N\%)+CC) - SVC
12350 NEXT N\%
12351 IF UP\% = 1 THEN 12360
12352 LPRINT "PERIOD COST SUMMARY"
12353 LPRINT "Environment Capital Cost Repair Cost" "Short. Cost Inven. Cost Total Cost"
12355 LPRINT "Environment # Units Start # Units End" "Operating Cost Per Unit"
GOTO 12400
CLS: COLOR 3,0: PRINT "PERIOD COST SUMMARY"
PRINT "Environment Capital Cost Repair Cost" "Short. Cost Inven. Cost Total Cost"
LOCATE 11,1
PRINT "Environment # Units Start # Units End" "Operating Cost Per Unit"
FOR N\% = 1 TO NO.ENVIR\%
C2 = 0: C3 = 0
IF SUMSP\%(N\%) = 0 THEN 12490
C2 = SMTR\%(N\%) * RC
C3 = (1-AVAILABILITY\%(N\%)) * SC * LTP\%
TC\%(N\%) = C1\%(N\%) + C2 + C3 + C4\%(N\%)
ACOST\%(N\%) = (TC\%(N\%)-C1\%(N\%)) / SUMSP\%(N\%)
12641 IF UP% = 1 THEN 12470
12642 LPRINT USING F7$;NO.ENVIR$(N%);C1(N%);C2;
12643 C3(C4(N%));T(J(N%))
12644 LPRINT USING F30$;NO.ENVIR$(N%);SUMSP%(N%);
12645 SUMSP2%(N%);ACOST(N%)
12666 GOTO 12510
12670 COLOR 2,0: LOCATE 4+N%,1
12680 PRINT USING F7$;NO.ENVIR$(N%);C1(N%);C2;
12690 LOCATE 12+N%,1
12500 PRINT USING F30$;NO.ENVIR$(N%);SUMSP%(N%);
12610 GOSUB 13040
12520 PB = l /(1+I*T%)
12530 C5(N%) = C5(N%) + C1(N%) * PB
12540 C6(N%) = C6(N%) + C2 * PB
12550 C7(N%) = C7(N%) + C3 * PB
12560 C8(N%) = C8(N%) + C4(N%) * PB
12570 C9(N%) = C9(N%) + TC(N%) * PB
12580 NEXT N%
12581 IF UP% = 1 THEN 12590
12590 LPRINT "Procurement costs for the period =";D%*PC
12610 GOTO 12640
12600 PRINT "Procurement costs for the period =";D%*PC
12610 PRC = PRC + llD%*PCl*PB: PCOSTIT%l
12611 IF UP% = 0 THEN 12640
12620 LOCATE 20,30: PRINT "Press any key to continue" 12630 A$=INKEY$: IF A$="" THEN 12630
12640 R% = NS% - 1: D% = 0
12650 RETURN
12660 ' SUBROUTINE TO CALCULATE AND PRINT PERIOD EQUIVALENT COST FOR MODEL RUN
12670 ' EQUIVALENT COST FOR MODEL RUN
12680 ' EQUIVALENT COST FOR MODEL RUN
12690 ' EQUIVALENT COST FOR MODEL RUN
12700 ' EQUIVALENT COST FOR MODEL RUN
12710 SSC1 = 0: SSC2 = 0: SSC3 = 0: SSC4 = 0: SSTC = 0
12711 IF UP% = 1 THEN 12720
12712 LPRINT "TOTAL COST SUMMARY"
12713 LPRINT "Environment Capital Cost Repair Cost" "Short. Cost Inven. Cost Total Cost"
12715 GOTO 12740
12720 CLS: COLOR 3,0: PRINT "TOTAL COST SUMMARY"
12730 PRINT "Environment Capital Cost Repair Cost" "Short. Cost Inven. Cost Total Cost"
12740 PB = 1 / ((1+I*T%)) / (((1+I*T%)-1)
12750 FOR N% = 1 TO NO.ENVIR%
12760 SC1 = C5(N%)* PB: SC2 = C6(N%)* PB
12770 SC5 = C7(N%)* PB: SC4 = C8(N%)* PB
12780 STC = C9(N%)* PB: SSC1 = SSC1 + SC1
12790 SSC2 = SSC2 + SC2: SSC3 = SSC3 + SC3
12800 SSC4 = SSC4 + SC4: SSTC = SSTC + STC
12801 IF UP% = 1 THEN 12810
12820 LPRINT USING F7$;NO.ENVIR$(N%);SC1;SC2;SC3;SC4;STC
12830 GOTO 12820
12810 PRINT USING F7$;NO.ENVIR$(N%);SC1;SC2;SC3;SC4;STC
12820 NEXT N%
12821 IF UP% = 1 THEN 12830
12822 LPRINT "Procurement costs per period =";PRC*PB
12823 GOTO 12840
12830 PRINT "Procurement costs per period =";PRC*PB
12840 SSTC = SSTC + (PRC*PB)
12841 IF UP% = 1 THEN 12850
12842 LPRINT
12843 LPRINT USING F7$;"TOTALS";SC1;SC2;SC3;SC4;STC
12844 GOTO 12870
12850 PRINT: COLOR 10,0
12860 PRINT USING F7$;"TOTALS";SSC1;SSC2;SSC3;SSC4;STC
12870 RETURN
12880 ' SUBROUTINE TO SAVE PERIOD BY PERIOD
12890 ' AVAILABILITY FOR PRINTER LISTING
12900 ' AVAILABILITY FOR PRINTER LISTING
12910 ' AVAILABILITY FOR PRINTER LISTING
12920 ' AVAILABILITY FOR PRINTER LISTING
SUBROUTINE TO SAVE PERIOD BY PERIOD

LOGISTICS POLICY COST DATA FOR PRINTER LISTING

IF N7 = 2 THEN 13100
GCOST(T%,1) = C1(N%): GCOST(T%,2) = C2
GCOST(T%,3) = C3: GCOST(T%,4) = C4(N%)
GCOST(T%,5) = TC(N%): GCOST(T%,6) = SUMSPX(N%)
GCOST(T%,7) = SUMSPY(N%)
GCOST(T%,8) = ACOST(N%): GOTO 13150
GCOST(T%+12,1) = C1(N%): GCOST(T%+12,2) = C2
GCOST(T%+12,3) = C3: GCOST(T%+12,4) = C4(N%)
GCOST(T%+12,5) = TC(N%): GCOST(T%+12,6) = SUMSPX(N%)
GCOST(T%+12,7) = SUMSPY(N%)
GCOST(T%+12,8) = ACOST(N%)
13150 RETURN

SUBROUTINE TO SUM PER END ITEM DEMAND ON REPAIR FACILITIES

MP(RL(A%)) = MP(RL(A%)) + (MTTRP(N%) * NODE(A%))
13220 RETURN

SUBROUTINE TO CALCULATE PERIOD DEMAND ON REPAIR FACILITIES

FOR VT% = 1 TO NO.RL%
GMP(T%,VT%) = GMP(T%,VT%) + (MP(VT%) * AVGSTREAM)
13250 NEXT VT%
13260 RETURN

SUBROUTINE TO GIVE PRINTER LISTING OF PERIOD SPAREPARTS AND WAREHOUSE REQUIREMENT SUMMARY

FOR N7 = 1 TO NO.R7%
LPRINT USING F56$JNN$1VV7.IJPN$JPSPR7.JF31VT7.IJ QPRIMEJTCPRIMEJRLH7.
NEXT N7.
13500 FOR N7 = 1 TO 12: LPRINT: NEXT
13520 RETURN

SUBROUTINE FOR PRINTER LISTING OF WAREHOUSE DEMAND TOTALS FOR PERIOD

LPRINT USING F57$J "Total warehouse requirement repair level ", N7"=":WH(N%)
13600 NEXT N7
13610 FOR N7 = 1 TO 12: LPRINT: NEXT
13620 RETURN
"INTRO" PROGRAM LISTING

This section of the program familiarizes the user with the operation and concepts of the modal call subroutines that display "INTRO" screens

CHAIN TO FIRST INPUT PROGRAM, "INPUT1"

END OF MAIN PROGRAM (INTRO)

SCREEN DRIVER SUBROUTINE

ALL OTHER SCREEN SUBRoutines REFERTo THIS SUBROUTINE DURING INTERACTIVE SESSIONS WITH THE USER OF THE MODEL

save "SGSUB.bas",a

701 REM PARAMETER REQ/OPT PURPOSE
702 REM SG.ROW% REQ Row (Not Altered)
703 REM SG.COL% REQ Column (Not Altered)
704 REM SG.LNG% REQ Length (Not Altered)
705 REM SG.UP%=1 OPT Uppercases input (default=0)
706 REM SG.DF$ OPT String for default input

710 REM ---------------Entry---------------
711 REM Numeric only gosub 770
712 REM Alphameric gosub 775
713 REM ---------------Output parms-------------
714 REM SG.REPLY$ - alphameric input
715 REM VAL(SG.REPLY$) - numeric input
720 REM -------------------------------
770 SG.HI%=77:SG.L0%=32:SG.MASK$=CHR$(1219):GOTO 780
775 SG.HI%=126:SG.L0%=32:SG.MASK$=CHR$(178)
780 LOCATE SG.ROW%,SG.COL%,1:SG.CO%=SG.COL%
785 SG.IN%0:SG.BTAB%=0
800 PRINT STR$(SG.LNG%,SG.MASK$)
820 IF SG.DF$="": THEN LOCATE SG.ROW%,SG.COL%,1
830 PRINT LEFT$(SG.DF$,SG.LNG%)
840 LOCATE SG.ROW%,SG.COL%,1
860 SG.REPLY$=INKEY$ SG.REPLY$="": THEN GOTO 860
880 IF LEN(SG.REPLY$) = 2 THEN GOTO 1080
900 IF SG.CHAR%=ASC(108) THEN SOUND 40,2:GOTO 1260
920 IF SG.CO%=SG.COL%+SG.LNG% THEN BEEP:GOTO 860
930 IF SG.CHAR%45 THEN GOTO 981
940 IF SG.CHAR%<SG.HI% AND SG.LO%>SG.CHAR%247 THEN SOUND 40,2:GOTO 1260
960 IF SG.CHAR%<SG.HI% OR SG.CHAR%<SG.LO% THEN BEEP:
GOTO 860

979 IF SG.CHAR$<96 AND SG.CHAR$>122 AND SG.UP%=1 THEN
    SG.REPLY$=CHR$(ASC(SG.REPLY$)+32)
981 SG.Y$="" NOT SG.INS% THEN GOTO 1000
982 FOR SG.I%=SG.CO% TO SG.COL%+SG.LNG%-1
983 SG.CHAR%=SCREEN(SG.ROW%,SG.I%)
985 SG.Y$=SG.Y$+CHR$(SG.CHAR%):NEXT SG.I%
986 SG.Y$=LEFT$(SG.REPLY$+SG.Y$,SG.C0%+SG.LNG%-SG.CO%)
987 PRINT SG.Y$
988 LOCATE SG.ROW%,SG.CO%+1,1;GOTO 1020
1000 PRINT SG.REPLY$;
1020 SG.CO%=SG.CO%+1
1040 IF SG.CO%=SG.COL%+SG.LNG% THEN LOCATE ,,0
1060 GOTO 860
1080 SG.CHAR%=ASC(RIGHT$(SG.REPLY$,1))
1082 IF SG.CHAR%<79 THEN SG.CO%=SG.CO%+1:LOCATE ,SG.CO%,1;GOTO 860
1084 IF SG.CHAR%<=17 THEN GOTO 1100
1086 IF SG.CO%=SG.CO%+1:SG.INS%=NOT SG.INS%:GOTO 860
1088 FOR SG.I%=SG.CO% TO SG.COL%+SG.LNG%-1;PRINT SG.MASK$;
         NEXT SG.I%:LOCATE ,SG.CO%,1:GOTO 860
1100 IF SG.CHAR%<>77 THEN GOTO 1160
1120 IF SG.CO%=SG.CO%+1:SG.LNG%=SG.LNG%-1 THEN BEEP;GOTO 860
1140 SG.CO%=SG.CO%+1:PRINT CHR$(28); SG.INS%=0:GOTO 860
1160 IF SG.CHAR%<75 THEN GOTO 1220
1180 IF SG.CO%=1 THEN BEEP;GOTO 860
1200 SG.CO%=SG.CO%-1:PRINT CHR$(29); SG.INS%=0:LOCATE ,,1:GOTO 860
1220 IF SG.CHAR%=82 THEN SG.CO%=SG.CO%-1:SG.INS%=1:GOTO 900
1222 IF SG.CHAR%<>73 THEN SG.INS%=0:LOCATE ,SG.CO%,1:GOTO 860
1224 IF SG.CHAR%=81 THEN SG.BTAB%=2:
1226 IF SG.CHAR%=68 THEN SG.BTAB%=3:
1228 IF SG.CHAR%=59 THEN SG.BTAB%=4:
1230 IF SG.CHAR%=67 THEN SG.BTAB%=5:
1232 IF SG.CHAR%=66 THEN SG.BTAB%=6:
1240 IF SG.CHAR%<>83 THEN BEEP;GOTO 860
1241 SG.Y$=""
1242 IF SG.CO%=SG.CO%+SG.LNG% THEN BEEP;GOTO 860
1243 FOR SG.I%=SG.CO% TO SG.CO%+SG.LNG%-1
1244 SG.CHAR%=SCREEN(SG.ROW%,SG.I%)
1246 SG.Y$=SG.Y$+CHR$(SG.CHAR%):NEXT SG.I%
1247 LOCATE SG.ROW%,SG.CO%,1:GOTO 860
1260 SG.REPLY$=SG.REPLY$+CHR$(SG.CHARY.)
1280 FOR SG.I%=0 TO SG.LNG%-1
1281 SG.CHAR%=SCREEN(SG.ROW%,SG.CO%+SG.I%)
1300 IF SG.CHAR%<>46 AND SG.UP%=1 AND SG.LO%<>46 THEN
         GOTO 1560
1320 IF SG.CHAR%<>46 THEN SG.UP%=1
1340 IF SG.CHAR%=ASC(SG.MASK$) THEN GOTO 1400
1360 SG.REPLY$=SG.REPLY$+CHR$(SG.CHARY.)
1380 NEXT SG.I%
1400 IF SG.HI%=126 THEN LOCATE SG.ROW%,SG.CO%,0;
         PRINT LEFT$(SG.REPLY$+SPACE$(SG.LNG%),SG.LNG%)
         :GOTO 1440
1420 LOCATE SG.ROW%,SG.CO%,0
1440 PRINT RIGHT$(SPACE$(SG.LNG%)+SG.REPLY$+SPACE$(SG.LNG%))
1460 IF NOT SG.DEFU% THEN DEF NFG$(FILE$)
         =RIGHT$(STR$(FILE$),LEN(STR$(FILE$))-1)
1411 COLOR 7,0
1465 KEY OFF
1464 SG.DEFU%=-1:SG.BTAB%=0
1466 LOCATE 25,1;COLOR 15,0
1468 IF MSG$="" THEN PRINT TAB(79), ELSE PRINT MSG$;
         TAB(79)="SOUND 340,2;SOUND 32767,1;SOUND 340,2"
1470 MSG$="";COLOR 7,0;RETURN
INTRO SCREEN SUBROUTINE

2000 ON REQ% GOSUB 2052,2046,2042,2024,2034,2030,2038
2001 RETURN
2002 ENTRY-------------ENTRY TYPE -------------SUBROUTINE-
2003 1 DISPLAY SCREEN ONLY !ERASE DATA
2004 2 DISPLAY SCREEN & DATA ELEMENTS
2005 3 DISPLAY DATA ELEMENTS ONLY
2006 4 INPUT ALL DATA ELEMENTS
2007 5 INPUT ONE ELEMENT BY RELATIVE FLD
2008 6 UPDATE ALL DATA ELEMENTS
2009 7 UPDATE ONE DATA ELEMENT BY REL FLD
2010 ---------------ENTRY TYPE -------------SUBROUTINE-

2016 RETURN

SG.DF$=SCR$
2020 SG.UP%=1:SG.ROH%=24:SG.COL%=74:SG.LNG%=1
2021 COLOR 15,1:GOSUB 775
2022 SCR$=SG.REPLY$:RETURN

2024 GOSUB 1462:GOSUB 2053
2026 IF SG.BTAB%=0 THEN GOSUB 2020 ELSE GOSUB 2018 'SCR$
2028 RETURN
2030 GOSUB 1462
2031 GOSUB 2018 'SCR$
2032 IF SG.BTAB%=2 THEN RETURN
2033 RETURN
2035 GOSUB 1462
2036 IF FLD%<31 THEN ON FLD% GOSUB 2020
2037 RETURN 'FIELDS HIGHER THAN 60 NOT INCLUDED ABOVE
2038 GOSUB 1462
2039 IF FLD%<31 THEN ON FLD% GOSUB 2018
2040 RETURN 'FIELDS HIGHER THAN 60 NOT INCLUDED ABOVE
2042 GOSUB 1462
2043 LOCATE 24,74:COLOR 15,1:PRINT USING "!JSCR$J"
2045 RETURN
2046 GOSUB 2052
2048 GOSUB 2043
2050 RETURN
2051 LOCATE 25,1:COLOR 1,0:PRINT""
2052 COLOR 8,0:CLS:GOSUB 1462
2053 COLOR 2,0
2054 LOCATE 1,1:PRINT"
2055 COLOR 24,0:LOCATE 2,40:PRINT "|"
2056 COLOR 8,0:LOCATE 3,10:PRINT "|
2057 COLOR 6,0:LOCATE 3,31:PRINT "|
2058 COLOR 5,0:LOCATE 3,41:PRINT "|"
2059 COLOR 6,0:LOCATE 4,11:PRINT "|
2060 COLOR 5,0:LOCATE 4,31:PRINT "|"
2061 COLOR 6,0:LOCATE 4,51:PRINT "|
2062 COLOR 5,0:LOCATE 4,71:PRINT "|
2063 COLOR 6,0:LOCATE 5,11:PRINT "|
2064 COLOR 5,0:LOCATE 5,31:PRINT "|
2065 COLOR 6,0:LOCATE 5,51:PRINT "|
2066 COLOR 5,0:LOCATE 5,71:PRINT "|
2067 COLOR 6,0:LOCATE 6,11:PRINT "|
2068 COLOR 5,0:LOCATE 6,31:PRINT "|
2069 COLOR 6,0:LOCATE 6,51:PRINT "|
2070 COLOR 5,0:LOCATE 6,71:PRINT "|
2071 COLOR 6,0:LOCATE 7,11:PRINT "|
2072 COLOR 5,0:LOCATE 7,31:PRINT "|
2073 COLOR 6,0:LOCATE 7,51:PRINT "|
2074 COLOR 5,0:LOCATE 7,71:PRINT "|
2075 COLOR 6,0:LOCATE 8,11:PRINT "|
2076 COLOR 5,0:LOCATE 8,31:PRINT "|
2077 COLOR 6,0:LOCATE 8,51:PRINT "|
2078 COLOR 5,0:LOCATE 8,71:PRINT "|
2079 COLOR 6,0:LOCATE 9,11:PRINT "|
2080 COLOR 5,0:LOCATE 9,31:PRINT "|
2081 COLOR 6,0:LOCATE 9,51:PRINT "|
2082 COLOR 5,0:LOCATE 9,71:PRINT "|
2083 COLOR 6,0:LOCATE 10,11:PRINT "|
2084 COLOR 5,0:LOCATE 10,31:PRINT "|
2085 COLOR 6,0:LOCATE 10,51:PRINT "|
2086 COLOR 5,0:LOCATE 10,71:PRINT "|
2087 COLOR 6,0:LOCATE 11,11:PRINT "|
2088 COLOR 5,0:LOCATE 11,31:PRINT "|
2089 COLOR 6,0:LOCATE 11,51:PRINT "|
2090 COLOR 5,0:LOCATE 11,71:PRINT "|
2091 COLOR 6,0:LOCATE 12,11:PRINT "|
2092 COLOR 5,0:LOCATE 12,31:PRINT "|
2093 COLOR 6,0:LOCATE 12,51:PRINT "|
2094 COLOR 5,0:LOCATE 12,71:PRINT "|
2095 COLOR 6,0:LOCATE 13,11:PRINT "|
2096 COLOR 5,0:LOCATE 13,31:PRINT "|
2097 COLOR 6,0:LOCATE 13,51:PRINT "|
2098 COLOR 5,0:LOCATE 13,71:PRINT "|
2099 COLOR 6,0:LOCATE 14,11:PRINT "|
2100 COLOR 5,0:LOCATE 14,31:PRINT "|"
2102 COLOR 8,0:LOCATE 6,35:PRINT 
2104 COLOR 8,0:LOCATE 6,39:PRINT 
2106 COLOR 8,0:LOCATE 6,43:PRINT 
2108 COLOR 24,0:LOCATE 6,47:PRINT 
2110 COLOR 8,0:LOCATE 6,51:PRINT 
2112 COLOR 8,0:LOCATE 6,55:PRINT 
2114 COLOR 8,0:LOCATE 6,60:PRINT 
2116 COLOR 8,0:LOCATE 6,64:PRINT 
2118 COLOR 8,0:LOCATE 6,68:PRINT 
2120 COLOR 8,0:LOCATE 6,72:PRINT 
2122 COLOR 8,0:LOCATE 6,76:PRINT 
2124 COLOR 8,0:LOCATE 6,79:PRINT 
2126 COLOR 8,0:LOCATE 7,3:PRINT 
2128 COLOR 8,0:LOCATE 7,7:PRINT 
2130 COLOR 8,0:LOCATE 7,11:PRINT 
2132 COLOR 8,0:LOCATE 7,15:PRINT 
2134 COLOR 4,0:LOCATE 7,23:PRINT 
2136 COLOR 4,0:LOCATE 7,27:PRINT 
2138 COLOR 4,0:LOCATE 7,31:PRINT 
2140 COLOR 4,0:LOCATE 7,35:PRINT 
2142 COLOR 4,0:LOCATE 7,39:PRINT 
2144 COLOR 7,0:LOCATE 7,43:PRINT 
2146 COLOR 7,0:LOCATE 7,47:PRINT 
2148 COLOR 7,0:LOCATE 7,51:PRINT 
2150 COLOR 7,0:LOCATE 7,55:PRINT 
2152 COLOR 7,0:LOCATE 7,59:PRINT 
2154 COLOR 7,0:LOCATE 7,63:PRINT 
2156 COLOR 14,0:LOCATE 7,67:PRINT 
2158 COLOR 14,0:LOCATE 7,71:PRINT 
2160 COLOR 14,0:LOCATE 7,75:PRINT 
2162 COLOR 14,0:LOCATE 7,79:PRINT 
2164 COLOR 8,0:LOCATE 8,3:PRINT 
2166 COLOR 8,0:LOCATE 8,7:PRINT 
2168 COLOR 8,0:LOCATE 8,11:PRINT 
2170 COLOR 8,0:LOCATE 8,15:PRINT 
2172 COLOR 8,0:LOCATE 8,19:PRINT 
2174 COLOR 8,0:LOCATE 8,23:PRINT 
2176 COLOR 8,0:LOCATE 8,27:PRINT 
2178 COLOR 8,0:LOCATE 8,31:PRINT 
2180 COLOR 8,0:LOCATE 8,35:PRINT 
2182 COLOR 8,0:LOCATE 8,39:PRINT 
2184 COLOR 8,0:LOCATE 8,43:PRINT 
2186 COLOR 8,0:LOCATE 8,47:PRINT 
2188 COLOR 8,0:LOCATE 8,51:PRINT 
2190 COLOR 8,0:LOCATE 8,55:PRINT 
2192 COLOR 8,0:LOCATE 8,59:PRINT 
2194 COLOR 8,0:LOCATE 8,63:PRINT 
2196 COLOR 8,0:LOCATE 8,67:PRINT 
2198 COLOR 8,0:LOCATE 8,71:PRINT 
2200 COLOR 8,0:LOCATE 8,75:PRINT 
2202 COLOR 8,0:LOCATE 8,79:PRINT 
2204 COLOR 8,0:LOCATE 9,3:PRINT 
2206 COLOR 8,0:LOCATE 9,7:PRINT 
2208 COLOR 8,0:LOCATE 9,11:PRINT 
2210 COLOR 8,0:LOCATE 9,15:PRINT 
2212 COLOR 8,0:LOCATE 9,19:PRINT 
2214 COLOR 8,0:LOCATE 9,23:PRINT 
2216 COLOR 8,0:LOCATE 9,27:PRINT 
2218 COLOR 8,0:LOCATE 9,31:PRINT 
2220 COLOR 8,0:LOCATE 9,35:PRINT 
2222 COLOR 8,0:LOCATE 9,39:PRINT 
2224 COLOR 8,0:LOCATE 9,43:PRINT 
2226 COLOR 8,0:LOCATE 9,47:PRINT 
2228 COLOR 24,0:LOCATE 9,51:PRINT 
2230 COLOR 8,0:LOCATE 9,55:PRINT 
2232 COLOR 8,0:LOCATE 9,59:PRINT 
2234 COLOR 8,0:LOCATE 9,63:PRINT 
2236 COLOR 8,0:LOCATE 9,67:PRINT 
2238 COLOR 8,0:LOCATE 9,71:PRINT 
2240 COLOR 8,0:LOCATE 9,75:PRINT 
2242 COLOR 8,0:LOCATE 9,79:PRINT 
2244 COLOR 8,0:LOCATE 10,1:PRINT 
2246 COLOR 8,0:LOCATE 10,7:PRINT 
2248 COLOR 8,0:LOCATE 10,11:PRINT
2252 COLOR 8,0:LOCATE 10,15:PRINT "|";
2254 COLOR 8,0:LOCATE 10,19:PRINT "|"
2256 COLOR 8,0:LOCATE 10,21:PRINT "|"
2258 COLOR 8,0:LOCATE 10,27:PRINT "|"
2260 COLOR 8,0:LOCATE 10,31:PRINT "|"
2262 COLOR 8,0:LOCATE 10,35:PRINT "|"
2264 COLOR 8,0:LOCATE 10,39:PRINT "|"
2266 COLOR 8,0:LOCATE 10,41:PRINT "|"
2268 COLOR 24,0:LOCATE 10,47:PRINT "|"
2270 COLOR 8,0:LOCATE 10,51:PRINT "|"
2272 COLOR 8,0:LOCATE 10,55:PRINT "|"
2274 COLOR 8,0:LOCATE 10,59:PRINT "|"
2276 COLOR 8,0:LOCATE 10,61:PRINT "|"
2278 COLOR 8,0:LOCATE 10,67:PRINT "|"
2280 COLOR 8,0:LOCATE 10,71:PRINT "|"
2282 COLOR 8,0:LOCATE 10,75:PRINT "|"
2284 COLOR 8,0:LOCATE 10,79:PRINT "|"
2286 COLOR 3,0:LOCATE 11,1:PRINT "|"
2288 COLOR 8,0:LOCATE 11,7:PRINT "|"
2290 COLOR 8,0:LOCATE 11,11:PRINT "|"
2292 COLOR 8,0:LOCATE 11,15:PRINT "|"
2294 COLOR 8,0:LOCATE 11,19:PRINT "|"
2296 COLOR 4,0:LOCATE 11,20:PRINT "|"
2298 COLOR 8,0:LOCATE 11,27:PRINT "|"
2300 COLOR 8,0:LOCATE 11,31:PRINT "|"
2302 COLOR 8,0:LOCATE 11,35:PRINT "|"
2304 COLOR 8,0:LOCATE 11,39:PRINT "|"
2306 COLOR 7,0:LOCATE 11,43:PRINT "|"
2308 COLOR 24,0:LOCATE 11,47:PRINT "|"
2310 COLOR 8,0:LOCATE 11,51:PRINT "|"
2312 COLOR 8,0:LOCATE 11,55:PRINT "|"
2314 COLOR 8,0:LOCATE 11,59:PRINT "|"
2316 COLOR 14,0:LOCATE 11,61:PRINT "|"
2318 COLOR 8,0:LOCATE 11,67:PRINT "|"
2320 COLOR 8,0:LOCATE 11,71:PRINT "|"
2322 COLOR 8,0:LOCATE 11,75:PRINT "|"
2324 COLOR 8,0:LOCATE 11,79:PRINT "|"
2326 COLOR 8,0:LOCATE 12,5:PRINT "|"
2328 COLOR 8,0:LOCATE 12,11:PRINT "|"
2330 COLOR 8,0:LOCATE 12,15:PRINT "|"
2332 COLOR 8,0:LOCATE 12,19:PRINT "|"
2334 COLOR 8,0:LOCATE 12,23:PRINT "|"
2336 COLOR 8,0:LOCATE 12,31:PRINT "|"
2338 COLOR 8,0:LOCATE 12,35:PRINT "|"
2340 COLOR 8,0:LOCATE 12,39:PRINT "|"
2342 COLOR 24,0:LOCATE 12,45:PRINT "|"
2344 COLOR 8,0:LOCATE 12,51:PRINT "|"
2346 COLOR 8,0:LOCATE 12,55:PRINT "|"
2348 COLOR 8,0:LOCATE 12,59:PRINT "|"
2350 COLOR 8,0:LOCATE 12,65:PRINT "|"
2352 COLOR 8,0:LOCATE 12,71:PRINT "|"
2354 COLOR 8,0:LOCATE 12,75:PRINT "|"
2356 COLOR 8,0:LOCATE 12,79:PRINT "|"
2358 COLOR 5,0:LOCATE 13,5:PRINT "|"
2360 COLOR 8,0:LOCATE 13,11:PRINT "|"
2362 COLOR 8,0:LOCATE 13,15:PRINT "|"
2364 COLOR 8,0:LOCATE 13,19:PRINT "|"
2366 COLOR 8,0:LOCATE 13,23:PRINT "|"
2368 COLOR 8,0:LOCATE 13,31:PRINT "|"
2370 COLOR 8,0:LOCATE 13,35:PRINT "|"
2372 COLOR 8,0:LOCATE 13,39:PRINT "|"
2374 COLOR 7,0:LOCATE 13,45:PRINT "|"
2376 COLOR 8,0:LOCATE 13,51:PRINT "|"
2378 COLOR 8,0:LOCATE 13,55:PRINT "|"
2380 COLOR 8,0:LOCATE 13,59:PRINT "|"
2382 COLOR 14,0:LOCATE 13,65:PRINT "|"
2384 COLOR 8,0:LOCATE 13,71:PRINT "|"
2386 COLOR 8,0:LOCATE 13,75:PRINT "|"
2388 COLOR 8,0:LOCATE 13,79:PRINT "|"
2390 COLOR 8,0:LOCATE 14,9:PRINT "|"
2392 COLOR 8,0:LOCATE 14,13:PRINT "|"
2394 COLOR 8,0:LOCATE 14,19:PRINT "|"
2396 COLOR 8,0:LOCATE 14,29:PRINT "|"
2398 COLOR 8,0:LOCATE 14,33:PRINT "|"
2400 COLOR 8,0:LOCATE 14,39:PRINT "|"
INTRO SCREEN SUBROUTINE

ENTRY = ENTRY TYPE = SUBROUTINE

DISPLAY SCREEN ONLY (ERASE DATA) 5052
DISPLAY SCREEN & DATA ELEMENTS 5046
DISPLAY DATA ELEMENTS ONLY 5042
INPUT ALL DATA ELEMENTS 5024
INPUT ONE ELEMENT BY RELATIVE FLD 5034
UPDATE ALL DATA ELEMENTS 5030
UPDATE ONE DATA ELEMENT BY REL FLD 5038

SG.DF$ = SCR$
SG.UP% = 1:SG.ROM%=23:SG.COL%=73:SG.LNG%=1
COLOR 15,1 :GOSUB 779
IF SG.BTAB% = 0 THEN GOSUB 5020 ELSE GOSUB 5018 'SCR$
RETURN
GOSUB 1462:GOSUB 5053
IF FLD% < 31 THEN ON FLD% GOSUB 5020 ELSE GOSUB 5018 'SCR$
RETURN
GOSUB 1462
GOSUB 5018 'SCR$
IF SG.BTAB% > 2 THEN RETURN
RETURN
GOSUB 1462
GOSUB 1462
IF FLD%<31 THEN ON FLO% GOSUB 5018
RETURN
RETURN
GOSUB 1462
LOCATE 23,73:COLOR 15,1:PRINT USING "!";SCR$;
RETURN
GOSUB 5052
LOCATE 25,1:COLOR 2,0
COLOR 3,0:LOCATE 2,28:PRINT "MULTI - STREAM CONCEPT"
COLOR 13,0:LOCATE 7,6:PRINT "AGE3"
COLOR 7,0:LOCATE 7,40:PRINT "AGE2"
COLOR 7,0:LOCATE 7,52:PRINT "AGE1"
COLOR 7,0:LOCATE 7,56:PRINT "AGE1"
COLOR 7,0:LOCATE 7,67:PRINT "AGE1"
COLOR 7,0:LOCATE 7,67:PRINT "AGE1"
COLOR 7,0:LOCATE 7,67:PRINT "AGE1"
COLOR 7,0:LOCATE 7,67:PRINT "AGE1"
COLOR 7,0:LOCATE 7,67:PRINT "AGE1"
"AGE1,AGE2,... = age of end items"

5176 COLOR 3:LOCATE 17,6:PRINT "la lb.........";
5179 PRINT "=" end items operating in failure"
5180 COLOR 3:LOCATE 18,25:PRINT "environments A and B"
5181 COLOR 3:LOCATE 20,6
5182 PRINT "la lb la...... = a stream"
5184 COLOR 3:LOCATE 21,23:PRINT "items have failed"
5185 PRINT "or all end items are retired"
5186 LOCATE 23,1:PRINT "Enter one of the following";
5187 "R to go back one screen, F to go forward"
5188 COLOR 15,0:LOCATE 25,73:PRINT " ";
5189 COLOR 3,0:RETURN
5200 INTRO SCREEN SUBROlJTINE
5201 ENTRY--------------ENTRY TYPE ------------SUBROUTINE-
5202 ENTRY ------------ENTRY TYPE ------------SUBROUTINE-
5203 1 DISPLAY SCREEN ONLY (ERASE DATA) 6052
5204 2 DISPLAY SCREEN & DATA ELEMENTS 6046
5205 3 DISPLAY DATA ELEMENTS ONLY 6042
5206 4 INPUT ALL DATA ELEMENTS 6024
5207 5 INPUT ONE ELEMENT BY RELATIVE FLO 6034
5208 6 UPDATE ALL DATA ELEMENTS 6030
5209 7 UPDATE ONE DATA ELEMENT BY REL FLO 6038
5211 SG.DF$=SCR$ 6020 SG.UP%=1:SG.ROH%=23:SG.COL%=74:SG.LNG%=1
5212 COLOR 15,1:GOSUB 775
5213 SCR$=SG.REPLY$:RETURN
5214 GOSUB 1462:GOSUB 6053
5215 IF SG.BTAB%=0 THEN GOSUB 6020 ELSE GOSUB 6018 'SCR$
5216 RETURN
5218 SG.BTAB%=0 THEN GOSUB 6020 ELSE GOSUB 6018 'SCR$
5220 GOSUB 1462
5221 IF FLD%<31 THEN ON FLO% GOSUB 6018 6022 RETURN
5223 IF FLD%<31 THEN ON FLO% GOSUB 6018
5224 RETURN
5225 LOCATE 23,74:COLOR 15,1:PRINT "USING ";
5226 COLOR 2,0 6027 GOSUB 1462
5228 IF FLD%<31 THEN ON FLO% GOSUB 6018
5229 GOSUB 1462
5230 RETURN
5231 GOSUB 6018 'SCR$
5232 IF SG.BTABX>2 THEN RETURN
5233 RETURN
5234 GOSUB 1462
5235 IF FLD%<21 THEN ON FLDF GOSUB 6020
5236 RETURN
5237 RETURN
5238 GOSUB 1462
5239 IF FLD%<21 THEN ON FLDF GOSUB 6018
5240 RETURN
5241 RETURN
5242 GOSUB 1462
5243 LOCATE 25,74:COLOR 15,1:PRINT USING "!",SCR$
5244 RETURN
5246 GOSUB 6052
5247 GOSUB 6048
5248 GOSUB 6045
5249 RETURN
5250 LOCATE 25,1:COLOR , 0:PRINT" ";
5252 COLOR , 8:CLS:GOSUB 1462 5253 COLOR 2:0
5254 COLOR 3:0:LOCATE 2,26
5255 PRINT "MAINTENANCE TREE CONCEPT"
5256 LOCATE 4,1:PRINT " The replaceable items being";
5257 "evaluated by this logistics model are"
5258 LOCATE 5,1:PRINT " referred to as end items."
5259 "Each end item is broken into repairable or"
5260 LOCATE 6,1:PRINT " replaceable components and"
5261 "then into subcomponents and so on until"
5262 LOCATE 7,1:PRINT " a spare part level is reached."
5263 "This breakdown produces a maintenance"
5264 LOCATE 8,1:PRINT " tree."
5265 COLOR 10,0:LOCATE 8,11:PRINT "See the next screen"
5266 "for a sample maintenance tree."
5267 COLOR 6,0:LOCATE 10,4:PRINT "Maintenance Tree Terminology:"
5268 COLOR 6,0:LOCATE 12,4:PRINT "node - each"
5269 "component on the tree represents a node"
5270 COLOR 6,0:LOCATE 14,4:PRINT "bottom of the tree node"
5271 " this is a node where failure and repair data is"
5272 COLOR 6,0:LOCATE 15,30:PRINT "known"
5274 COLOR 6,0:LOCATE 15,30:PRINT "known"
5276 COLOR 6,0:LOCATE 17,4:PRINT "stockable items"
"- parts needed to repair the component listed at a";
6078 COLOR 6,0:LOCATE 18,30:PRINT "bottom of the tree node";
6080 COLOR 6,0:LOCATE 20,4:PRINT "repair level"
"- maintenance facility which must perform the repair"
6082 COLOR 2,0:LOCATE 23,3:PRINT "Enter one of the"
"following (R to go back one screen, F to go forward)";
6084 COLOR 15,1:LOCATE 23,7:PRINT "";
6086 COLOR 2,0:RETURN
6990 ' INTRO SCREEN SUBROUTINE
6991 ' ENTRY
6992
7000 ON REQ% GOSUB 7052,7046,7024,7034,7030,7038
7001 RETURN
7002 ' ENTRY TYPE -----------------------------SUBROUTINE-
7003 1 DISPLAY SCREEN ONLY (ERASE DATA) 7052
7004 2 DISPLAY SCREEN & DATA ELEMENTS 7046
7006 3 DISPLAY DATA ELEMENTS ONLY 7042
7008 4 INPUT ALL DATA ELEMENTS 7024
7010 5 INPUT ONE ELEMENT BY RELATIVE FLD 7054
7012 6 UPDATE ALL DATA ELEMENTS 7050
7014 7 UPDATE ONE DATA ELEMENT BY REL FLD 7058
7016 ' ------------------------------------------
7018 SG.DFS$=SCR$ 7020 SG.UP%=24:SG.COL%=74
7021 SG.LNG%=15:COLOR 15,1:GOSUB 775
7022 SCR$=SG.REPLY$:RETURN
7024 GOSUB 1462:GOSUB 7053
7026 IF SG.BTAB%=0 THEN GOSUB 7020 ELSE GOSUB 7018 'SCR$
7028 RETURN
7030 GOSUB 1462
7031 GOSUB 7018 'SCR$
7032 IF SG.BTAB%>2 THEN RETURN
7033 RETURN
7034 GOSUB 1462
7035 IF FLD%<31 THEN ON FLD% GOSUB 7020
7037 RETURN 'FIELDS HIGHER THAN 60 NOT INCLUDED ABOVE
7038 GOSUB 1462
7039 IF FLD%<31 THEN ON FLD% GOSUB 7018
7041 RETURN 'FIELDS HIGHER THAN 60 NOT INCLUDED ABOVE
7042 GOSUB 1462
7043 LOCATE 24,74:COLOR 15,1:PRINT USING "!";SCR$
7045 RETURN
7046 GOSUB 7052
7048 GOSUB 7043
7050 RETURN
7051 LOCATE 25,1:COLOR 0:PRINT "";
7052 COLOR 1,8:CLS:GOSUB 1462
7053 COLOR 2,0
7054 LOCATE 1,1:PRINT "" ;
7056 LOCATE 2,1:PRINT "";
7058 COLOR 10,0:LOCATE 2,40:PRINT "car"
7060 COLOR 2,0:LOCATE 2,43:PRINT "";
7062 LOCATE 3,1:PRINT "" ;
7064 LOCATE 4,1:PRINT "";
7066 LOCATE 5,1:PRINT "";
7068 LOCATE 6,1:PRINT "";
7070 LOCATE 7,1:PRINT "";
7072 COLOR 10,0:LOCATE 7,7:PRINT "cooling"
7074 COLOR 2,0:LOCATE 7,14:PRINT "";
7076 COLOR 10,0:LOCATE 7,19:PRINT "drivetrain"
7078 COLOR 2,0:LOCATE 7,29:PRINT "";
7080 COLOR 10,0:LOCATE 7,36:PRINT "electrical"
7082 COLOR 2,0:LOCATE 7,46:PRINT "";
7084 COLOR 10,0:LOCATE 7,55:PRINT "other"
7086 COLOR 2,0:LOCATE 7,60:PRINT "";
7088 COLOR 10,0:LOCATE 7,70:PRINT "fatal"
7090 COLOR 2,0:LOCATE 7,75:PRINT "";
7092 LOCATE 8,1:PRINT "";
7094 COLOR 10,0:LOCATE 8,7:PRINT "system"
7096 COLOR 2,0:LOCATE 8,13:PRINT "";
7098 COLOR 10,0:LOCATE 8,19:PRINT "combustion"
7100 COLOR 2,0:LOCATE 8,29:PRINT "";
7102 COLOR 10,0:LOCATE 8,36:PRINT "system"
7104 COLOR 2,0:LOCATE 8,44:PRINT "";
The previous screen was a partial maintenance tree for an automobile.

- were bottom of the tree nodes
- were stockable items
- mean time to repair
248

8072 COLOR 6,0:LOCATE 12,6:PRINT "MTBF";
8074 COLOR 3,0:LOCATE 12,37
8075 PRINT "- mean time between failures";
8076 COLOR 6,0:LOCATE 14,6:PRINT "RL";
8078 PRINT "- repair level";
8080 COLOR 3,0:LOCATE 18,6:PRINT "The next screen shows"
8081 PRINT "the maintenance tree limitations for this"
8082 PRINT "following (R to go back one screen, F to go forward)"
8084 COLOR 3,0:LOCATE 23,2:PRINT "max. # nodes = 126"
8085 COLOR 3,0:LOCATE 23,8:PRINT "max. levels of indenture = 5"
8086 COLOR 3,0:LOCATE 23,12:PRINT "The next screen shows"
8087 PRINT "the maintenance tree limitations for this"
8088 PRINT "following (R to go back one screen, F to go forward)"
8090 RETURN
10990 •
10991 • 10992 • 10993 •
INTRO SCREEN
SUBROUTINE
10999 ON REQ7 GOSUB 11052,11046,11042,11024, 11034,11030,11038
11001 RETURN
11002 ' ENTRY-------------------ENTRY TYPE --------------SUBROUTINE-
11003 ' 1 DISPLAY SCREEN ONLY (ERASE DATA) 11052
11004 ' 2 DISPLAY SCREEN & DATA ELEMENTS 11046
11005 ' 3 DISPLAY DATA ELEMENTS ONLY 11042
11006 ' 4 INPUT ALL DATA ELEMENTS 11024
11007 ' 5 INPUT ONE ELEMENT BY RELATIVE FLD 11034
11008 ' 6 UPDATE ALL DATA ELEMENTS 11030
11009 ' 7 UPDATE ONE DATA ELEMENT BY REL FLD 11038
11010 ' -----------------------------------
11011 SG.DF$=SCR$ 11020 SG.UP%=1:SG.ROHX=23:SG.COL1.=6:SG.LNGY.=1
11012 COLOR 0,7 :GOSUB 775
11013 SCR$=SG.REPLY$:RETURN
11014 IF SG.BTAB%=0 THEN GOSUB 11020 ELSE GOSUB 11018 'SCR$
11015 RETURN
11016 GOSUB 1462
11017 IF FLD%<31 THEN ON
11018 IF FLD%>60 THEN RETURN
11019 GOSUB 1462
11020 LOCATE 25,6:COLOR 0,7:PRINT USING "!";SCR$;
11021 RETURN
11022 GOSUB 1462
11023 IF FLD%<31 THEN ON
11024 IF FLD%>60 THEN RETURN
11025 GOSUB 1462
11026 LOCATE 25,6:COLOR 0,7:PRINT USING "!";SCR$;
11027 RETURN
11028 GOSUB 1462
11029 IF FLD%<31 THEN ON
11030 IF FLD%>60 THEN RETURN
11031 GOSUB 1462
11032 LOCATE 25,6:COLOR 0,7:PRINT USING "!";SCR$;
11033 RETURN
11034 GOSUB 1462
11035 IF FLD%<31 THEN ON
11036 IF FLD%>60 THEN RETURN
11037 GOSUB 1462
11038 IF FLD%<31 THEN ON
11039 IF FLD%>60 THEN RETURN
11040 GOSUB 1462
11041 LOCATE 25,6:COLOR 0,7:PRINT USING "!";SCR$;
11042 RETURN
11043 GOSUB 1462
11044 GOSUB 11052
11045 GOSUB 11062
11046 GOSUB 11068
11047 LOCATE 25,1:COLOR 7:PRINT " ";
11048 GOSUB 11052,8:CLS:GOSUB 1462
11049 GOSUB 11052
11050 RETURN
11051 LOCATE 25,1:COLOR 7:PRINT " ";
11052 COLOR 8:CLS:GOSUB 1462
11053 COLOR 0,7
11054 LOCATE 1,1:PRINT SPACE$(80);
11055 LOCATE 2,1:PRINT " ";
11056 LOCATE 2,7:LOCATE 2,1:PRINT SPACE$(80);
11057 LOCATE 3,1:PRINT SPACE$(80);
11058 LOCATE 4,1:PRINT " ";
11059 LOCATE 0,7:LOCATE 4,1:PRINT SPACE$(80);
11060 LOCATE 5,1:PRINT SPACE$(80);
11061 LOCATE 6,1:PRINT "MAINTENANCE REQUIREMENTS PLANNING"
11062 LOCATE 7,1:PRINT SPACE$(80);
11063 LOCATE 8,1:PRINT " ";
11064 LOCATE 9,1:PRINT SPACE$(80);
11065 LOCATE 10,1:PRINT " REPAIRABLE ITEM POPULATIONS"
11066 LOCATE 11,1:PRINT SPACE$(80);
11067 LOCATE 12,1:PRINT SPACE$(80);
11068 LOCATE 13,1:PRINT SPACE$(80);
11069 LOCATE 14,1:PRINT " ";
11070 LOCATE 14,1:PRINT " ";
11071 LOCATE 16,1:PRINT " ";
11072 LOCATE 17,1:PRINT SPACE$(80);
11182 LOCATE 18,1:PRINT " ";
11184 COLOR 12,7:LOCATE 18,35:PRINT "MMMMMMMMM ";
11186 COLOR 0,7:LOCATE 18,45:PRINT SPACE$(36);
11188 LOCATE 19,1:PRINT " ";
11190 COLOR 9,7:LOCATE 19,35:PRINT "MMMMMMMMM";
11192 COLOR 12,7:LOCATE 19,44:PRINT " ";
11194 COLOR 0,7:LOCATE 19,46:PRINT SPACE$(35);
11196 LOCATE 20,1:PRINT " ";
11198 COLOR 12,7:LOCATE 20,37:PRINT " ";
11200 COLOR 0,7:LOCATE 20,47:PRINT SPACE$(34);
11202 LOCATE 21,1:PRINT SPACE$(80);
11204 LOCATE 22,1:PRINT SPACE$(80);
11206 LOCATE 23,1
11209 PRINT "Enter F to go forward to the next screen";
11210 LOCATE 24,1:PRINT SPACE$(79);
11212 COLOR 2,0:RETURN
1. PROGRAM LISTING FOR "INPUT1"

2. DIMENSION ARRAYS

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SCREEN 0,1

71. CNT6%=0: T%=0: COLOR 3,0,8: CLS

72. LOCATE 2,30: PRINT "DATA CHOICE"

73. COLOR 2,0: LOCATE 6,24

74. PRINT "1...Give Printer Listing of all Output Screens"

75. LOCATE 10,24: PRINT "2...Give Printer Listing of End of "

76. PRINT "Model Summaries Only"

77. LOCATE 10,24: PRINT "Enter 1 or 2 >",UB%

78. IF UB% <> 3 THEN 130

79. IF UB% = 4 THEN END

80. USER INPUTS CHOICE OF PRINTER LISTINGS

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135. LTP$="days": LTP%=30: LMR%=12: NO.ENVIR%=2: CC=350000!


137. SPMAx%=2: NO.RL%=3

138.
INITIALIZE VARIABLES

FOR N% = 1 TO 40
    ST%(N%)=0:IP%(N%)=0:SP%(N%)=0:SP2%(N%)=0
NEXT
R1%=0:PA%=1:0%=0:SIG%=0:CNT%=0
FOR N% = 1 TO 41
    C5%(N%)=0:C6%(N%)=0:C7%(N%)=0:C8%(N%)=0
NEXT

152: GOSUB TO SCREEN SUBROUTINE
153: INPUT PERIOD UNIT, LENGTH OF PERIOD,
154: LENGTH OF MODEL RUN,
155: AND # OF FAILURE ENVIRONMENTS
156:
157:
158: REQ%=2:GOSUB 4000
159: REQ%=6:GOSUB 4000
160:
161: SET VALUE FOR LX% DEPENDING ON
162: PERIOD UNIT CHOSEN BY USER OF MODEL
163:
164:
169: IF ASCILTP$=68 OR ASCILTP$=100 THEN 200
170: IF ASCILTP$=87 OR ASL(TP$)=119 THEN 210
171: IF ASCILTP$=77 OR ASCILTP$=109 THEN 220
172: LX%=365: LTP$="year": GOTO 230
173: LX%=1: LTP$="day": GOTO 230
174: LX%=7: LTP$="week": GOTO 230
175: LX%=30: LTP$="month": GOTO 230
176: IF SCR$ = "R" THEN 158
177:
178: GOSUB TO SCREEN SUBROUTINE
179: INPUT COST DATA FOR END ITEM
180:
181:
182:
183: REQ%=2:GOSUB 5000
184: REQ%=6:GOSUB 5000
185: I=II/100
186: IF SCR$ = "R" THEN 158
187:
188: GOSUB TO SCREEN SUBROUTINE
189: INPUT TYPE POPULATION BEING EVALUATED,
190: INVENTORY LOT SIZING METHOD, AND
191: # OF REPAIR LEVELS
192:
193:
194:
195: REQ%=2:GOSUB 8000
196: REQ%=6:GOSUB 8000
197: FOR N% = 1 TO NO.RL%
198: FOR VT%= 1 TO LMR%: GHPIVT%,N%) = 0: NEXT
199: NEXT
200: IF SPHA% = 3 THEN NS%=1
201: IF SCR$ = "R" THEN 240
202: IF UB% = 1 OR UB% = 2 THEN 370
203:
204: GOSUB TO SCREEN SUBROUTINE
205: DISPLAY LIBRARY OF FAILURE CURVES
206:
207:
208: GOSUB TO SCREEN SUBROUTINE
209: INPUT AND STORE NODE FAILURE DATA
210: LOOP THROUGH ONCE FOR EACH ENVIRONMENT
211:
212:
213:
214: FOR N% = 1 TO NO.ENVIR%
215: IF UB% = 1 THEN 396
IF UB% = 2 THEN 405

input data

GOSUB 7500

SCREEN 0,1

IF UB% = 3 THEN 405

more input data for example

GOSUB 2000

store data

ON N% GOSUB 11050,11150,11250,11350

gosub screen subroutines for period by period

probability of component failure if data exists

GOSUB 20000

REG% = 2: GOSUB 21000

REG% = 6: GOSUB 21000

gosub screen subroutines

input demand, end item retirement age, and end item book value at retirement

GOSUB 20500

REG% = 2: GOSUB 17000

REG% = 6: GOSUB 17000

NEXT

CHAIN TO "INPUT2"

SCREEN SUBROUTINE DRIVER

note: not included - see Screen Subroutine Driver, lines 700-1486 in INTRO

SUBROUTINE CONTAINING FAILURE DATA FOR EXAMPLE

2000 NODE1%(27)=27: NN$1(27)= "Freshwa.Pump": CDF1%(27)=3
2001 RL(27)=2: MTBF1(27)=8.33: MTTR1(27)=1
2002 DEMAND%1(1)=140: BV1(1)=15000: RA1(1)=500
2003 NO.ENVIR$1(1)= "SUPPORT"
2004 NO.EVIR%1(1)= "COLD ZONE"
2010 CDF2%(27)=2: MTBF2(27)=5.57: MTTR2(27)=1
2011 DEMAND%2(1)=60: BV2(1)=15000: RA2(1)=500: NODE2%(27)=27
2015 NODE1%(28)=28: NN$1(28)= "Seawater Pump": CDF1%(28)=3
2016 RL%(28)=2: MTBF1(28)=20.63: MTTR1(28)=1.2
2017 CDF2%(28)=2: MTBF2(28)=13.9: MTTR2(28)=1.2
2018 NODE2%(28)=28
2020 NODE1%(29)=29: NN$1(29)= "Hyd. Pump": CDF1%(29)=3
2021 RL%(29)=1: MTBF1(29)=33.33: MTTR1(29)=1.2
2022 CDF2%(29)=2: MTBF2(29)=22.23: MTTR2(29)=1.2
2023 NODE2%(29)=29
2025 NODE1%(32)=32: NN$1(32)= "Eng.Coolant HE": CDF1%(32)=4
SCREEN SUBROUTINE

INPUT PERIOD UNIT, LENGTH OF PERIOD, LENGTH OF
MODEL RUN, AND # OF FAILURE ENVIRONMENTS

RETURN
COLOR 15.1:LOCATE 8,68:PRINT "",";
COLOR 3.0:LOCATE 12,1
PRINT "Operating environment information;";
LOCATE 14,1:PRINT "It is possible for units of the"
"same age to have different failure rates";
LOCATE 15,1:PRINT "due to the respective environments"
"in which the units operate.;"
COLOR 2.0:LOCATE 17,1:PRINT "In how many different"
"failure environments will your population of";
LOCATE 18,1
PRINT "units operate? I limit of 5 environments)"
COLOR 15,1:LOCATE 18,44:PRINT " ";
COLOR 3.0:LOCATE 23,1:PRINT "Enter one of the"
following (r to go back, f to go forward);
COLOR 15,1:LOCATE 23,73:PRINT " ";
GOSUB 25083
COLOR 2.0:RETURN
IF SG.BTAB%<5 THEN RETURN ELSE GOTO 4092
SUBROUTINE INPUT END ITEM
COST
DATA note: subroutine not listed - This subroutine is
very similar to the screen subroutine in lines 4000 - 4168.
SUBROUTINE TO DISPLAY LIBRARY OF FAILURE CURVES
KEY OFF
PI=3.141593
SCREEN 2,0
LOCATE 1,28: PRINT "LIBRARY OF FAILURE CURVES"
LOCATE 1,1: PRINT "1": LOCATE 8,1
PRINT "0 t"
LINE (10,10)-(10,60): LINE (10,60)-190,60)
LINE (113,15)-190,15,,&HCCCC
LINE (10,60)-190,15,,&HCCCC
LINE (220,60),80,,PI/2,PI,7/13
CIRCLE (1220,60),80,,3*PI/2,0,8/13
CIRCLE (1280,10),80,,3*PI/2,0,8/15
LINE (1283,15)-1360,15,,&HCCCC
LINE (1410,10)-1410,60)
CIRCLE (1490,16),40,,3*PI/2,0,8/15
CIRCLE (1580,59),40,,PI/2,PI,7/13
LOCATE 10,1: PRINT " 1) Uniform 2) Exponential"
PRINT " 3) Exp. Increase 4) Normal 5) Bathtub"
PRINT "The above curves are cumulative"
"distributions of failure rate"
"probabilities. To interpret the curves read"
"the x axis as time and the y axis"
"as the probability of a failure. So the"
"curves represent the probability of"
"failure of an item during that item's"
"life cycle."
PRINT "If one of these curves appears to"
"represent the failure characteristics of the"
PRINT "item that you are evaluating, enter either"
"1, 2, 3, 4, or 5 on the next screen"
PRINT "when you are asked for the failure rate"
"curve shape and the model will compute"
If you have period by period failure data available for certain items, enter 6. If you have failure rate curve shape and 0 for MTBF, enter 6 for failure rate curve shape and 0 for MTBF. Input failure data later. Enter one of the following (r to go back, f to go forward) > ";SCR$

SUBROUTINE FOR LISTING FAILURE INPUT EXPLANATION

YH=l: GOSUB 7000
LOCATE 12,17 PRINT "INPUT MAINTENANCE TREE DATA BY FAILURE ENVIRONMENT"

PRINT: PRINT " Enter a 1 or 2 word description of the operating environment for units"
LOCATE 15,40: LINE INPUT >",NO.ENVIR$1tV.J
PRINT: PRINT " You will be asked to enter known failure rate information about the item being evaluated. The information will be entered by maintenance tree node."
PRINT: PRINT " You must input the following " information when prompted:

LOCATE 24,50: PRINT " press any key to continue"
A$=INKEY$: IF A$ = "" THEN 7577
CLS: GOSUB 7000
LOCATE 12,1: PRINT " Node 6 represents the chance of fatal failure of the end item. Data for this node must be provided as input as prompted, then continue with the input of information for other bottom nodes of the tree nodes."
LOCATE 16,1: PRINT " Node # >",AX
IF A%=0 THEN 7900
LOCATE CSRLIN-1,24: PRINT " Node Name: ",AX$1A%
GOSUB 10500
NEXT
GOTO 7900
GOTO 770
RETURN

SUBROUTINE FOR INPUT TYPE OF POPULATION, INVENTORY LOT SIZING CHOICE, AND # OF REPAIR LEVELS

note: subroutine not included This screen subroutine is similar to subroutine in lines 4000 - 4168.
SCREEN SUBROUTINE

INPUT NODE FAILURE DATA

LOCATE CSRLIN-1,50
INPUT "Failure rate curve shape > ", CDF$
PRINT USING " ",LTP$
LOCATE CSRLIN-1,1: INPUT " MTBF >", MTBF
MTBF = MTBF/LTP$
LOCATE CSRLIN-1,24
PRINT USING " ",LTP$
LOCATE CSRLIN-1,26: INPUT "MTTR >",MTTR
IF NX>1 THEN LOCATE CSRLIN-1,50
PRINT "Repair Level > ",RL%(AX)\): GOTO 10580
LOCATE CSRLIN-1,50: INPUT "Repair Level > ",RL%(AX)
ON N% GOSUB 11000,11100,11200,11300,11400
CNT6% = CNT6% + 1
IF CNT6% = 1 THEN LOCATE CSRLIN-1,50
RETURN

SUBROUTINES FOR SAVING NOOE FAILURE DATA

FOR P% = 1 TO 126
MTBF1(P%)=MTBF: NODE1(P%)=A% 
CDF1(P%)=CDF%(P%): HTTR1(P%)=HTTR
NEXT
RETURN

FOR P% = 1 TO 126
MTBF2(P%)=MTBF1(P%): NODE2(P%)=A% 
CDF2(P%)=CDF1(P%): HTTR2(P%)=HTTR
NEXT
RETURN

FOR P% = 1 TO 126
MTBF3(P%)=MTBF2(P%): NODE3(P%)=A% 
CDF3(P%)=CDF2(P%): HTTR3(P%)=HTTR
NEXT
RETURN

FOR P% = 1 TO 126
MTBF4(P%)=MTBF3(P%): NODE4(P%)=A% 
CDF4(P%)=CDF3(P%): HTTR4(P%)=HTTR
NEXT
RETURN

screen subroutine similar to subroutine in lines 4000 - 4168.
SUBROUTINE FOR CONTROLLING THE INPUT OF
PERIOD BY PERIOD NODE DATA

20000 VZ=1
20010 FOR VT% = 1 TO 126
20020 IF NODEP%(VT%) = 0 THEN 20050
20030 AA%(VZ%) = NODEP%(VT%); VZ% = VZ% + 1
20035 IF VZ% < 16 THEN 20050
20040 REQ% = 2: GOSUB 21000
20042 REQ% = 6: GOSUB 21000
20045 GOSUB 20500
20047 VZ% = 1
20050 NEXT VT%
20070 RETURN
20050 IF VT% > 126 THEN VT% = 126
20055 FOR A% = 1 TO VT%
20050 IF CDFP%(A%) = 0 THEN 20540
20052 MTBF = MTBF%(A%); CDF% = CDFP%(A%)
20053 MTTR = MTTR%(A%)
20054 ON NZ GOSUB 11000, 11100, 11200, 11300
20054 NEXT
20054 FOR A% = 1 TO 15: AA%(A%) = 0: NEXT
200550 RETURN
20090 ' INPUT PERIOD BY PERIOD NODE FAILURE DATA
20092 ' SCREEN SUBROUTINE
20093 ' note: subroutine not listed -
20096 ' This screen subroutine is similar to
20097 ' the subroutine in lines 4000 - 4168.
PROGRAM LISTING FOR "INPUT2"

DISPLAY FAILURE DATA IF PREVIOUS MODEL
RUN DATA HAS BEEN SAVED
DATA CHANGES MAY BE MADE
OUTER LOOP ONCE FOR EACH ENVIRONMENT
INNER LOOP ONCE FOR EACH NODE

FOR N% = 1 TO NO.ENVIRX
  retrieve data
  ON N% GOSUB 11050,11150,11250,11350
  FOR P% = 1 TO 126
    IF CDFP%(P%) <> 6 THEN
      FOR A% = 1 TO 40: MTBFPIA%J=0: NEXT
      gosub screen subroutine
      review and allow changes to failure data
      REQ%=2:GOSUB 25000
      REQ%=6:GOSUB 25000
      FILE$ = "O:" + STR$(N%) + STR$(P%)
      OPEN "r",#2,FILE$5,4
      FIELD #2, 4 AS NODE$
      FOR A% = 1 TO LMR%
        LSET NODE$ = MKSfHTBFPfA%): PUT U,A%
      NEXT A%
      CLOSE #2
      NEXT P%
    NEXT P%
  NEXT N%
GOSUB SCREEN SUBROUTINE
INPUT PROCUREMENT POLICY CHOICE
GOSUB SCREEN SUBROUTINE
INPUT DATA FOR THE PROCUREMENT POLICY CHOSEN

FOR P% = 1 TO 126
  IF CDFP%(P%) <> 6 THEN
    IF SCR$ = "R" THEN 430
    ST%(1)=IP%(1): AMT%(1)=IP%(1)
    CHAIN TO STOCKABLE ITEM INPUT PROGRAMS
    IF EOQ INVENTORY LOT SIZING IS BEING USED,
      CHAIN TO "IV2"
    IF NO INVENTORY LOT SIZING IS BEING USED,
      CHAIN TO "IV1"
    IF SPHA% = 1 THEN CHAIN "IV1",10,ALL
    IF SPHA% = 2 THEN CHAIN "IV2",10,ALL
    IF SPHA% = 3 THEN CHAIN "b:final",100,ALL
    END OF MAIN PROGRAM (INPUT2)
SCREEN SUBROUTINE DRIVER
note: subroutine not listed - See INTRO program for a listing of this subroutine.

SCREEN SUBROVTINE
Input Procurement Policy SELECTION

ON REQ% GOSUB 9064,9058,9052,9030,9044,9038,9048
RETURN

SG.V%=PL%;SG.MSK$="":GOSUB 1471
SG.RO%<22:SG.COL%>75:SG.LNG%>1
COLOR 15,1:GOSUB 770
PL%=VALISG.REPLY$J:RETURN
SG.DF$=SCR$:RETURN
COLOR 15,1:GOSUB 775
SCR$=SG.REPLY$:RETURN
GOSUB 1462
GOSUB 9018 'PL$
IF SG.BTAB%>2 THEN GOTO 9128
GOSUB 9024 SG.BTAB%=1 THEN GOTO 9039 'SCR$
IF SG.BTAB%>2 THEN RETURN
RETURN
GOSUB 1462
LOCATE 22,75:COLOR 15,1:PRINT USING "#JPL$J"
LOCATE 24,75:COLOR 15,1:PRINT USING "!JSCR$J"
RETURN
GOSUB 9064
GOSUB 9053 RETURN
LOCATE 25,1:COLOR 0:PRINT " ";
COLOR 0,8:CLS:GOSUB 1462
COLOR 3,0:LOCATE 2,23
PRINT "PROCUREMENT POLICY SELECTION"
LOCATE 4,1:PRINT " This will be the policy that"
LOCATE 41,6:PRINT "Until Upper Limit is Reached"
COLOR 2,0:LOCATE 6,1:PRINT " 1....Continuous"
COLOR 10,0:LOCATE 6,19
PRINT "Uniform Procurement"
LOCATE 6,1:PRINT " 2...."
LOCATE 6,0:PRINT "Uniform Procurement"
LOCATE 2,0:LOCATE 8,27
PRINT " Until Upper Limit is Reached"
LOCATE 10,1:PRINT " 3......One Initial"
LOCATE 12,1:PRINT " 4....Continuous"
LOCATE 12,8:PRINT "Block Procurement"
COLOR 10,0:LOCATE 10,20:PRINT "Block Procurement"
LOCATE 12,8:PRINT "Block Procurement"
LOCATE 14,19:PRINT "Increasing Procurement"
COLOR 2,0:LOCATE 12,25
PRINT " with Replenishment as Units Fail Fatally"
LOCATE 14,1:PRINT " 5.....Continuous"
LOCATE 14,41:PRINT " Amounts"
LOCATE 16,1:PRINT " 6...."
COLOR 10,0:LOCATE 16,8:PRINT "Increasing Procurement"
LOCATE 18,19:PRINT "Decreasing Procurement"
COLOR 2,0:LOCATE 18,30
PRINT " Until Upper Limit is Reached"
LOCATE 18,1:PRINT " 7.....Continuous"
LOCATE 18,42:PRINT "Amounts"
LOCATE 20,1:PRINT " 8...."
COLOR 2,0:LOCATE 20,20
PRINT " Until Upper Limit is Reached"
LOCATE 22,1:PRINT " 9.....Other"
COLOR 3,0:LOCATE 22,58
PRINT "Enter either 1,2,3,4,5,6,7,8,or 9"
LOCATE 24,2:PRINT "Enter F to go forward"
COLOR 15,1:LOCATE 22,75:PRINT " ";
LOCATE 24,75:PRINT " ";
COLOR 2,0:RETURN
IF SG.BTAB%<5 THEN RETURN ELSE GOTO 9041
SCREEN SUBROUTINE
INPUT DATA FOR PROCUREMENT POLICY
UNIFORM PROCUREMENT UNTIL UPPER LIMIT IS REACHED

note: subroutine not listed - This screen subroutine is similar to the subroutine in lines 9000 - 9128.

SCREEN SUBROUTINE
INPUT DATA FOR PROCUREMENT POLICY
CONTINUOUS UNIFORM PROCUREMENT

note: subroutine not listed - This screen subroutine is similar to the subroutine in lines 9000 - 9128.

SCREEN SUBROUTINE
INPUT DATA FOR PROCUREMENT POLICY
BLOCK PROCUREMENT WITH REPLENISHMENT

note: subroutine not listed - This screen subroutine is similar to the subroutine in lines 9000 - 9128.

SCREEN SUBROUTINE
INPUT DATA FOR PROCUREMENT POLICY
ONE BLOCK PROCUREMENT

note: subroutine not listed - This screen subroutine is similar to the subroutine in lines 9000 - 9128.

SUBROUTINES FOR RETRIEVING NODE FAILURE DATA

FOR P% = 1 TO 126
MTBF(P%) = MTBF1(P%): NODEP% = NODE1(P%)
CDF(P%) = CDF1(P%): MTTR1(P%) = MTTR1(P%)
NEXT
RETURN

FOR P% = 1 TO 126
MTBF(P%) = MTBF2(P%): NODEP% = NODE2(P%)
CDF(P%) = CDF2(P%): MTTR2(P%) = MTTR2(P%)
NEXT
RETURN

FOR P% = 1 TO 126
MTBF(P%) = MTBF3(P%): NODEP% = NODE3(P%)
CDF(P%) = CDF3(P%): MTTR3(P%) = MTTR3(P%)
NEXT
RETURN

FOR P% = 1 TO 126
MTBF(P%) = MTBF4(P%): NODEP% = NODE4(P%)
CDF(P%) = CDF4(P%): MTTR4(P%) = MTTR4(P%)
NEXT
RETURN

SCREEN SUBROUTINE
INPUT DATA FOR PROCUREMENT POLICY
INCREASING PROCUREMENT TO UPPER LIMIT

note: subroutine not listed -
This screen subroutine is similar to
the subroutine in lines 9000 - 9128.

SCREEN SUBROUTINE
INPUT DATA FOR PROCUREMENT POLICY
INCREASING PROCUREMENT AMOUNTS

note: subroutine not listed -
This screen subroutine is similar to
the subroutine in lines 9000 - 9128.

SCREEN SUBROUTINE
INPUT DATA FOR PROCUREMENT POLICY
DECREASING PROCUREMENT TO UPPER LIMIT

note: subroutine not listed -
This screen subroutine is similar to
the subroutine in lines 9000 - 9128.

SCREEN SUBROUTINE
INPUT DATA FOR PROCUREMENT POLICY
DECREASING PROCUREMENT AMOUNTS

note: subroutine not listed -
This screen subroutine is similar to
the subroutine listed in lines 9000 - 9128.

SCREEN SUBROUTINE
INPUT DATA FOR PROCUREMENT POLICY
OTHER PROCUREMENT POLICY

note: subroutine not listed -
This screen subroutine is similar to
the subroutine in lines 9000 - 9128.

SCREEN SUBROUTINE
DISPLAY AND ALLOW CHANGES TO NODE FAILURE DATA

note: subroutine not listed -
This screen subroutine is similar to
the subroutine in lines 9000 - 9128.
PROGRAM LISTING FOR "IV1"

GOSUB IF THE EXAMPLE IS BEING RUN OR
IF DATA FROM A PREVIOUS MODEL RUN IS BEING USED

IF UBX = 1 OR UBX = 2 THEN GOSUB 400

INPUT STOCKABLE ITEM DATA NECESSARY TO CALCULATE
SPARE PART AND WAREHOUSE REQUIREMENTS ONLY
LOOP ONCE FOR EACH NODE

FOR VX = 1 TO 126
FOR V% = 1 TO 10
   FILE4$ = "node" + STR$(V%)
   OPEN "i",11,FILE4$
   FOR N% = 1 TO 10
      IF EOF(11) THEN 470
      INPUT#, I$(N%),PN$(N%),QY(N%),SR(N%),PR(N%)
   NEXT N%
   CLOSE 1
   NEXT VX
   INITIALIZATION OF VARIABLES
   NEXT V%
   CHAIN TO PROGRAM "MAIN"
BEGIN MODEL CALCULATIONS

CHAIN "MAIN",100,ALL

END OF MAIN PROGRAM (IV1)

SUBROUTINE TO DISPLAY AND ALLOW CHANGES TO
NODE FAILURE DATA FOR EITHER EXAMPLE PROBLEM
OR DATA FROM PREVIOUS MODEL RUN

FOR VX = 1 TO 126
FOR V% = 1 TO 10
   IF NODE1(X%)(V%) = 0 THEN 170
   GOSUB screen subroutine input stockable item data
   INPUT#, I$(VX),PN$(VX),QY(VX),SR(VX),PR(VX)
   FILE4$ = "node" + STR$(V%) OPEN "i",11,FILE4$
   FOR N% = 1 TO 10
      IF EOF(11) THEN 470
      INPUT#, I$(N%),PN$(N%),QY(N%),SR(N%),PR(N%)
   NEXT N%
   REQ%=2:GOSUB 21000
   REQ%=6:GOSUB 21000
NEXT VX
SUBROUTINE TO DISPLAY AND ALLOW CHANGES TO
NODE FAILURE DATA FOR EITHER EXAMPLE PROBLEM
OR DATA FROM PREVIOUS MODEL RUN

CHAIN TO PROGRAM "MAIN"
BEGIN MODEL CALCULATIONS
500 FOR N% = 1 TO 10
510 IF QY(N%) = 0 THEN 530
520 PRINT#1, I%(N%), PN%(N%), SR%(N%), PR%(N%)
530 NEXT N%
540 CLOSE 1
550 FOR VT% = 1 TO 10
560 I$(VT%) = "": PN$(VT%) = "": QY(VT%) = 0: SR(VT%) = 0: PR(VT%) = 0
570 NEXT VT%
580 NEXT V%
590 RETURN 200

SCREEN SUBROUTINE DRIVER

NOTE: subroutine not listed - This subroutine is listed in lines 700 - 1486 in program INTRO.

SCREEN SUBROUTINE

INPUT, REVIEW, OR CHANGE STOCKABLE ITEM DATA

ON REQ% GOSUB 21784, 21778, 21652, 21390, 21644, 21518, 21648

RETURN

SG.DF$ = NN$(V%)
SG.ROH% = 6: SG.COL% = 16: SG.LNG% = 14: COLOR 10, 0: GOSUB 775
SG.ROH% = 11: SG.COL% = 5: SG.LNG% = 10: COLOR 10, 0: RETURN
SG.ROH% = 10: SG.COL% = 24: SG.LNG% = 7: COLOR 6, 0: GOSUB 1471
SG.ROH% = 11: SG.COL% = 34: SG.LNG% = 7: COLOR 6, 0: GOSUB 770
SG.ROH% = 11: SG.COL% = 52: SG.LNG% = 8: COLOR 6, 0: GOSUB 1471
SG.ROH% = 12: SG.COL% = 34: SG.LNG% = 7: COLOR 6, 0: GOSUB 770
SG.ROH% = 12: SG.COL% = 52: SG.LNG% = 8: COLOR 6, 0: GOSUB 1471
SG.ROH% = 12: SG.COL% = 71: SG.LNG% = 9: COLOR 6, 0: GOSUB 770
SG.ROH% = 12: SG.COL% = 34: SG.LNG% = 7: COLOR 6, 0: GOSUB 1471
SG.ROH% = 12: SG.COL% = 52: SG.LNG% = 8: COLOR 6, 0: GOSUB 1471
SG.ROH% = 12: SG.COL% = 71: SG.LNG% = 9: COLOR 6, 0: GOSUB 770
SG.ROH% = 12: SG.COL% = 34: SG.LNG% = 7: COLOR 6, 0: GOSUB 1471
SG.ROH% = 12: SG.COL% = 52: SG.LNG% = 8: COLOR 6, 0: GOSUB 1471
SG.ROH% = 12: SG.COL% = 71: SG.LNG% = 9: COLOR 6, 0: GOSUB 770
21262 IF (9) = VAL (SG.REPLY$) : RETURN
21264 SG.RW$ = 18: SG.COL$ = 2: SG.LNG$ = 15: COLOR 6,0 : GOSUB 775
21268 'I(9) = SG.REPLY$ : RETURN
21270 SG.DE$ = PN(10)
21272 SG.ROW$ = 18: SG.COL$ = 24: SG.LNG$ = 7: COLOR 6,0 : GOSUB 775
21274 PN(9) = SG.REPLY$ : RETURN
21276 IF SG.VV$ = PN(9) : SG.MSK$ = "###" : GOSUB 1471
21278 SG.ROW$ = 18: SG.COL$ = 34: SG.LNG$ = 7: COLOR 6,0 : GOSUB 770
21280 QY(9) = VAL (SG.REPLY$) : RETURN
21282 IF SG.VV$ = PR(9) : SG.MSK$ = "#" : GOSUB 1471
21284 SG.ROW$ = 18: SG.COL$ = 52: SG.LNG$ = 6: COLOR 6,0 : GOSUB 770
21286 SR(9) = VAL (SG.REPLY$) : RETURN
21288 SG.VV$ = PR(9) : SG.MSK$ = "###" : GOSUB 1471
21290 SG.ROW$ = 18: SG.COL$ = 71: SG.LNG$ = 6: COLOR 6,0 : GOSUB 770
21292 PR(9) = VAL (SG.REPLY$) : RETURN
21294 SG.DE$ = 'I(10)
21296 SG.ROW$ = 19: SG.COL$ = 5: SG.LNG$ = 15: COLOR 6,0 : GOSUB 775
21298 'I(10) = SG.REPLY$ : RETURN
21300 SG.DE$ = PN(10)
21302 SG.ROW$ = 19: SG.COL$ = 24: SG.LNG$ = 7: COLOR 6,0 : GOSUB 775
21304 PN(10) = SG.REPLY$ : RETURN
21306 SG.VV$ = QY(10) : SG.MSK$ = "###" : GOSUB 1471
21308 SG.ROW$ = 19: SG.COL$ = 34: SG.LNG$ = 7: COLOR 6,0 : GOSUB 770
21310 QY(10) = VAL (SG.REPLY$) : RETURN
21312 SG.VV$ = SR(10) : SG.MSK$ = "###" : GOSUB 1471
21314 SG.ROW$ = 19: SG.COL$ = 52: SG.LNG$ = 6: COLOR 6,0 : GOSUB 770
21316 SR(10) = VAL (SG.REPLY$) : RETURN
21318 SG.VV$ = PR(10) : SG.MSK$ = "###" : GOSUB 1471
21320 SG.ROW$ = 19: SG.COL$ = 71: SG.LNG$ = 6: COLOR 6,0 : GOSUB 770
21322 PR(10) = VAL (SG.REPLY$) : RETURN
21324 SG.DE$ = SCR$;
21326 SG.UP$ = 1: SG.ROW$ = 25: SG.COL$ = 56: SG.LNG$ = 1
21328 COLOR 15.1 : GOSUB 775
21330 SCR$ = SG.REPLY$ : RETURN
21332 GOSUB 1462
21334 GOSUB 2108: "$N(V$)
21336 IF SG.TB$ > 2 THEN GOTO 21828
21338 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21519: 'I(1)
21340 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21521: 'PN(1)
21342 IF SG.TB$ > 2 THEN GOTO 21828
21344 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21523: 'QY(1)
21346 IF SG.TB$ > 2 THEN GOTO 21828
21348 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21525: 'SR(1)
21350 IF SG.TB$ > 2 THEN GOTO 21828
21352 IF SG.TB$ > 2 THEN GOTO 21828
21354 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21527: 'PR(1)
21356 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21529: 'I(2)
21358 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21531: 'PN(2)
21360 IF SG.TB$ > 2 THEN GOTO 21828
21362 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21533: 'QY(2)
21364 IF SG.TB$ > 2 THEN GOTO 21828
21366 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21535: 'SR(2)
21368 IF SG.TB$ > 2 THEN GOTO 21828
21370 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21537: 'PR(2)
21372 IF SG.TB$ > 2 THEN GOTO 21828
21374 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21539: 'I(3)
21376 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21541: 'PN(3)
21378 IF SG.TB$ > 2 THEN GOTO 21828
21380 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21543: 'QY(3)
21382 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21545: 'SR(3)
21384 IF SG.TB$ > 2 THEN GOTO 21828
21386 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21547: 'PR(3)
21388 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21549: 'I(4)
21390 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21551: 'PN(4)
21392 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21553: 'QY(4)
21394 GOSUB 21024: SG.TB$ = 1 THEN GOTO 21555: 'SR(4)
21558 IF SG.BTAB%>2 THEN GOTO 21828
21559 GOSUB 21136 SG.BTAB%=1 THEN GOTO 21557 'PR(4)
21560 IF SG.BTAB%>2 THEN GOTO 21828
21561 GOSUB 21144 SG.BTAB%=1 THEN GOTO 21559 'I$(5)
21562 IF SG.BTAB%>2 THEN GOTO 21828
21563 GOSUB 21150 SG.BTAB%=1 THEN GOTO 21561 'PN$(5)
21564 IF SG.BTAB%>2 THEN GOTO 21828
21565 GOSUB 21156 SG.BTAB%=1 THEN GOTO 21563 'QY(5)
21566 IF SG.BTAB%>2 THEN GOTO 21828
21567 GOSUB 21162 SG.BTAB%=1 THEN GOTO 21565 'SR(5)
21568 IF SG.BTAB%>2 THEN GOTO 21828
21569 GOSUB 21168 SG.BTAB%=1 THEN GOTO 21567 'PR(5)
21570 IF SG.BTAB%>2 THEN GOTO 21828
21571 GOSUB 21174 SG.BTAB%=1 THEN GOTO 21569 'I$(6)
21572 IF SG.BTAB%>2 THEN GOTO 21828
21573 GOSUB 21180 SG.BTAB%=1 THEN GOTO 21571 'PN$(6)
21574 IF SG.BTAB%>2 THEN GOTO 21828
21575 GOSUB 21186 SG.BTAB%=1 THEN GOTO 21573 'QY(6)
21576 IF SG.BTAB%>2 THEN GOTO 21828
21577 GOSUB 21192 SG.BTAB%=1 THEN GOTO 21575 'SR(6)
21578 IF SG.BTAB%>2 THEN GOTO 21828
21579 GOSUB 21198 SG.BTAB%=1 THEN GOTO 21577 'PR(6)
21580 IF SG.BTAB%>2 THEN GOTO 21828
21581 GOSUB 21204 SG.BTAB%=1 THEN GOTO 21579 'I$(7)
21582 IF SG.BTAB%>2 THEN GOTO 21828
21583 GOSUB 21210 SG.BTAB%=1 THEN GOTO 21581 'PN$(7)
21584 IF SG.BTAB%>2 THEN GOTO 21828
21585 GOSUB 21216 SG.BTAB%=1 THEN GOTO 21583 'QY(7)
21586 IF SG.BTAB%>2 THEN GOTO 21828
21587 GOSUB 21222 SG.BTAB%=1 THEN GOTO 21585 'SR(7)
21588 IF SG.BTAB%>2 THEN GOTO 21828
21589 GOSUB 21228 SG.BTAB%=1 THEN GOTO 21587 'PR(7)
21590 IF SG.BTAB%>2 THEN GOTO 21828
21591 GOSUB 21234 SG.BTAB%=1 THEN GOTO 21589 'I$(8)
21592 IF SG.BTAB%>2 THEN GOTO 21828
21593 GOSUB 21240 SG.BTAB%=1 THEN GOTO 21591 'PN$(8)
21594 IF SG.BTAB%>2 THEN GOTO 21828
21595 GOSUB 21246 SG.BTAB%=1 THEN GOTO 21593 'QY(8)
21596 IF SG.BTAB%>2 THEN GOTO 21828
21597 GOSUB 21252 SG.BTAB%=1 THEN GOTO 21595 'SR(8)
21598 IF SG.BTAB%>2 THEN GOTO 21828
21599 GOSUB 21258 SG.BTAB%=1 THEN GOTO 21597 'PR(8)
21600 IF SG.BTAB%>2 THEN GOTO 21828
21601 GOSUB 21264 SG.BTAB%=1 THEN GOTO 21599 'I$(9)
21602 IF SG.BTAB%>2 THEN GOTO 21828
21603 GOSUB 21270 SG.BTAB%=1 THEN GOTO 21601 'PN$(9)
21604 IF SG.BTAB%>2 THEN GOTO 21828
21605 GOSUB 21276 SG.BTAB%=1 THEN GOTO 21603 'QY(9)
21606 IF SG.BTAB%>2 THEN GOTO 21828
21607 GOSUB 21282 SG.BTAB%=1 THEN GOTO 21605 'SR(9)
21608 IF SG.BTAB%>2 THEN GOTO 21828
21609 GOSUB 21288 SG.BTAB%=1 THEN GOTO 21607 'PR(9)
21610 IF SG.BTAB%>2 THEN GOTO 21828
21611 GOSUB 21294 SG.BTAB%=1 THEN GOTO 21609 'I$(10)
21612 IF SG.BTAB%>2 THEN GOTO 21828
21613 GOSUB 21300 SG.BTAB%=1 THEN GOTO 21611 'PN$(10)
21614 IF SG.BTAB%>2 THEN GOTO 21828
21615 GOSUB 21306 SG.BTAB%=1 THEN GOTO 21613 'QY(10)
21616 IF SG.BTAB%>2 THEN GOTO 21828
21617 GOSUB 21312 SG.BTAB%=1 THEN GOTO 21615 'SR(10)
21618 IF SG.BTAB%>2 THEN GOTO 21828
21619 GOSUB 21318 SG.BTAB%=1 THEN GOTO 21617 'PR(10)
21620 IF SG.BTAB%>2 THEN GOTO 21828
21621 GOSUB 21324 SG.BTAB%=1 THEN GOTO 21639 'SCR$
LIST STOCKABLE ITEMS
SO THAT SPARE PARTS REQUIREMENTS MAY BE CALCULATED

When needed, press the "F9" key to advance to bottom.

Enter F to continue
PROGRAM LISTING FOR "IV2"

GOSUB TO REVIEW OR MAKE CHANGES TO STOCKABLE ITEM DATA IF EXAMPLE IS BEING RUN OR IF DATA FROM A PREVIOUS MODEL RUN HAS BEEN SAVED

IF UB%=1 OR UB%=2 THEN GOSUB 400

INPUT STOCKABLE ITEM DATA FOR CALCULATING SPARE PARTS AND WAREHOUSING REQUIREMENTS USING EOQ LOT SIZING

LOOP ONCE FOR EACH NODE

FOR V%= 1 TO 126
  IF V%= 6 THEN 170
  IF NODE1%(V%) = 0 THEN 170
  gosub screen subroutine
  input data
  store data in disk files
  FILE4$ = "node" + STR$(V%)
  OPEN "o",#1,FILE4$
  FOR W. = 1 TO 10
    IF EOF1(W.) ELSE
      INPUT#1, I$1(W.), PN$1(W.), QYI(W.), SRI(W.), PRI(W.), CPI(W.), CHI(W.), LT(W.)
    NEXT W.
  CLOSE 1

  initialize variables

FOR VT%= 1 TO 10
  I$(VT%) = "": PN$(VT%) = "": QYI(VT%) = 0: SR(VT%) = 0: PR(VT%) = 0: CPI(VT%) = 0: CHI(VT%) = 0: LT(VT%) = 0
  NEXT VT%

CHAIN TO PROGRAM "MAIN"
BEGIN CALCULATIONS

CHAIN "MAIN",100,ALL

END OF MAIN PROGRAM (IV2)

SUBROUTINE FOR DISPLAYING AND CHANGING STOCKABLE ITEM DATA FROM EXAMPLE OR PREVIOUS MODEL RUN
475 CLOSE 1
480 REQ%=2:GOSUB 23000
490 REQ%=6:GOSUB 23000
495 OPEN "o",#1,FILE4$
500 FOR N%=1 TO 10
510 IF QVIN% = 0 THEN 530
520 PRINT Bl, I$(N%);"",P$(N%);","QV(N%);
      SR(N%);PR(N%);CP(N%);CH(N%);LT(N%)
530 NEXT N%
540 CLOSE 1
550 FOR VT%=1 TO 10
560 I$(VT%)=="":PN$(VT%)=="":QVIVT%=0:SRIVT%=0:PRIVT%=0:CPlvt%J=0:CHIVT%=0:LTIVT%=0
570 NEXT VT%
580 NEXT V%
590 RETURN
600 'SCREEN SUBROUTINE DRIVER
601 'note: subroutine not listed -
602 'See screen subroutine driver listing in lines 700 - 1486 of program INTRO.
603 'SCREEN SUBROUTINE
604 'INPUT STOCKABLE ITEM DATA FOR EOQ LOT SIZING
605 23000 ON REQ% GOSUB 24216, 24210, 24012, 23606, 24004, 23086, 24008
606 23002 RETURN
23018 SG.DF$=N$(V%)
23020 SG.ROKX=6:SG.COLX=16:SG.LNGX=14:COLOR 10,0 :GOSUB 775
23022 N$(V%)=I$(1)
23024 SG.DF$=I$(1)
23026 SG.ROW=11:SG.COL=5:SG.LNGX=15:COLOR 6,0 :GOSUB 775
23028 I$(1)=SG.REPLY$:RETURN
23030 SG.DF$=PN$(1)
23032 SG.ROW=11:SG.COL=22:SG.LNGX=7:COLOR 6,0 :GOSUB 775
23034 PN$(1)=SG.REPLY$:RETURN
23036 SG.VVQ=QV1:SG.MSK$="":GOSUB 1471
23038 SG.ROW=11:SG.COL=31:SG.LNGX=7:COLOR 6,0 :GOSUB 770
23040 QV(1)=VAL(SG.REPLY$:RETURN
23042 SG.VVQ=SR1:SG.MSK$="":GOSUB 1471
23044 SG.ROW=11:SG.COL=40:SG.LNGX=8:COLOR 6,0 :GOSUB 770
23046 SR(1)=VAL(SG.REPLY$:RETURN
23048 SG.VVQ=PR1:SG.MSK$="":GOSUB 1471
23050 SG.ROW=11:SG.COL=50:SG.LNGX=8:COLOR 6,0 :GOSUB 1471
23052 PR(1)=VAL(SG.REPLY$:RETURN
23054 SG.VVQ=CP1:SG.MSK$="":GOSUB 1471
23056 SG.ROW=11:SG.COL=59:SG.LNGX=7:COLOR 6,0 :GOSUB 1471
23058 CP(1)=VAL(SG.REPLY$:RETURN
23060 SG.VVQ=CH1:SG.MSK$="":GOSUB 1471
23062 SG.ROW=11:SG.COL=68:SG.LNGX=7:COLOR 6,0 :GOSUB 1471
23064 CH(1)=VAL(SG.REPLY$:RETURN
23066 SG.VVQ=LTI:SG.MSK$="":GOSUB 1471
23068 SG.ROW=11:SG.COL=76:SG.LNGX=3:COLOR 6,0 :GOSUB 1471
23070 LT(1)=VAL(SG.REPLY$:RETURN
23072 SG.DF$=I$(2)
23074 SG.ROW=12:SG.COL=5:SG.LNGX=15:COLOR 6,0 :GOSUB 775
23076 I$(2)=SG.REPLY$:RETURN
23078 SG.DF$=PN$(2)
23080 SG.ROW=12:SG.COL=22:SG.LNGX=7:COLOR 6,0 :GOSUB 775
23082 PN$(2)=SG.REPLY$:RETURN
23084 SG.VVQ=QV2:SG.MSK$="":GOSUB 1471
23086 SG.ROW=12:SG.COL=31:SG.LNGX=7:COLOR 6,0 :GOSUB 770
23088 QV(2)=VAL(SG.REPLY$:RETURN
23090 SG.VVQ=SR2:SG.MSK$="":GOSUB 1471
23092 SG.ROW=12:SG.COL=40:SG.LNGX=8:COLOR 6,0 :GOSUB 770
23094 SR(2)=VAL(SG.REPLY$:RETURN
23096 SG.VVQ=PR2:SG.MSK$="":GOSUB 1471
23098 SG.ROW=12:SG.COL=50:SG.LNGX=8:COLOR 6,0 :GOSUB 770
23100 PR(2)=VAL(SG.REPLY$:RETURN
23102 SG. VV$=CP(2): SG. MSK$="####.##": GOSUB 1471
23104 SG. ROH% = 12: SG. COL% = 59: SG. LNG% = 7: COLOR 6,0: GOSUB 770
23106 CP(2) = VAL(SG. REPLY$): RETURN
23108 SG. VV$=CH(2): SG. MSK$="####.##": GOSUB 1471
23110 SG. ROW% = 12: SG. COL% = 68: SG. LNG% = 7: COLOR 6,0: GOSUB 770
23112 CH(2) = VAL(SG. REPLY$): RETURN
23114 SG. VV$=LT(2): SG. MSK$="####.##": GOSUB 1471
23116 SG. ROW% = 12: SG. COL% = 76: SG. LNG% = 3: COLOR 6,0: GOSUB 770
23118 LT(2) = VAL(SG. REPLY$): RETURN
23120 SG. DF$ = I$(3)
23122 SG. ROW% = 13: SG. COL% = 5: SG. LNG% = 15: COLOR 6,0: GOSUB 775
23124 I$(3) = SG. REPLY$: RETURN
23126 SG. DF$ = PN$(3)
23128 SG. ROW% = 13: SG. COL% = 22: SG. LNG% = 7: COLOR 6,0: GOSUB 775
23130 PN$(3) = SG. REPLY$: RETURN
23132 SG. VV$=G(3): SG. MSK$="#####": GOSUB 1471
23134 SG. ROW% = 13: SG. COL% = 31: SG. LNG% = 7: COLOR 6,0: GOSUB 770
23136 G(3) = VAL(SG. REPLY$): RETURN
23138 SG. VV$=SR(3): SG. MSK$="#####": GOSUB 1471
23140 SG. ROW% = 13: SG. COL% = 40: SG. LNG% = 8: COLOR 6,0: GOSUB 770
23142 SR(3) = VAL(SG. REPLY$): RETURN
23144 SG. VV$=PR(3): SG. MSK$="#####": GOSUB 1471
23146 SG. ROW% = 13: SG. COL% = 50: SG. LNG% = 8: COLOR 6,0: GOSUB 770
23148 PR(3) = VAL(SG. REPLY$): RETURN
23150 SG. VV$=CP(3): SG. MSK$="#####": GOSUB 1471
23152 SG. ROW% = 13: SG. COL% = 59: SG. LNG% = 7: COLOR 6,0: GOSUB 770
23154 CP(3) = VAL(SG. REPLY$): RETURN
23156 SG. VV$=CH(3): SG. MSK$="#####": GOSUB 1471
23158 SG. ROW% = 13: SG. COL% = 68: SG. LNG% = 7: COLOR 6,0: GOSUB 770
23160 CH(3) = VAL(SG. REPLY$): RETURN
23162 SG. VV$=LT(3): SG. MSK$="#####": GOSUB 1471
23164 SG. ROW% = 13: SG. COL% = 76: SG. LNG% = 3: COLOR 6,0: GOSUB 770
23166 LT(3) = VAL(SG. REPLY$): RETURN
23168 SG. DF$ = I$(4)
23170 SG. ROW% = 14: SG. COL% = 5: SG. LNG% = 15: COLOR 6,0: GOSUB 775
23172 I$(4) = SG. REPLY$: RETURN
23174 SG. DF$ = PN$(4)
23176 SG. ROW% = 14: SG. COL% = 22: SG. LNG% = 7: COLOR 6,0: GOSUB 775
23178 PN$(4) = SG. REPLY$: RETURN
23180 SG. VV$=G(4): SG. MSK$="#####": GOSUB 1471
23182 SG. ROW% = 14: SG. COL% = 31: SG. LNG% = 7: COLOR 6,0: GOSUB 770
23184 G(4) = VAL(SG. REPLY$): RETURN
23186 SG. VV$=SR(4): SG. MSK$="#####": GOSUB 1471
23188 SG. ROW% = 14: SG. COL% = 40: SG. LNG% = 8: COLOR 6,0: GOSUB 770
23190 SR(4) = VAL(SG. REPLY$): RETURN
23192 SG. VV$=PR(4): SG. MSK$="#####": GOSUB 1471
23194 SG. ROW% = 14: SG. COL% = 50: SG. LNG% = 8: COLOR 6,0: GOSUB 770
23196 PR(4) = VAL(SG. REPLY$): RETURN
23198 SG. VV$=CP(4): SG. MSK$="#####": GOSUB 1471
23200 SG. ROW% = 14: SG. COL% = 59: SG. LNG% = 7: COLOR 6,0: GOSUB 770
23202 CP(4) = VAL(SG. REPLY$): RETURN
23204 SG. VV$=CH(4): SG. MSK$="#####": GOSUB 1471
23206 SG. ROW% = 14: SG. COL% = 68: SG. LNG% = 7: COLOR 6,0: GOSUB 770
23208 CH(4) = VAL(SG. REPLY$): RETURN
23210 SG. VV$=LT(4): SG. MSK$="#####": GOSUB 1471
23212 SG. ROW% = 14: SG. COL% = 76: SG. LNG% = 3: COLOR 6,0: GOSUB 770
23214 LT(4) = VAL(SG. REPLY$): RETURN
23216 SG. DF$ = I$(5)
23218 SG. ROW% = 15: SG. COL% = 5: SG. LNG% = 15: COLOR 6,0: GOSUB 775
23220 I$(5) = SG. REPLY$: RETURN
23222 SG. DF$ = PN$(5)
23224 SG. ROW% = 15: SG. COL% = 22: SG. LNG% = 7: COLOR 6,0: GOSUB 775
23226 PN$(5) = SG. REPLY$: RETURN
23228 SG. VV$=G(5): SG. MSK$="#####": GOSUB 1471
23230 SG. ROW% = 15: SG. COL% = 31: SG. LNG% = 7: COLOR 6,0: GOSUB 770
23232 G(5) = VAL(SG. REPLY$): RETURN
23234 SG. VV$=SR(5): SG. MSK$="#####": GOSUB 1471
23236 SG. ROW% = 15: SG. COL% = 40: SG. LNG% = 8: COLOR 6,0: GOSUB 770
23238 SR(5) = VAL(SG. REPLY$): RETURN
23240 SG. VV$=PR(5): SG. MSK$="#####": GOSUB 1471
23242 SG. ROW% = 15: SG. COL% = 50: SG. LNG% = 8: COLOR 6,0: GOSUB 770
23244 PR(5) = VAL(SG. REPLY$): RETURN
23246 SG. VV$=CP(5): SG. MSK$="#####": GOSUB 1471
23248 SG. ROW% = 15: SG. COL% = 59: SG. LNG% = 7: COLOR 6,0: GOSUB 770
23250 CP(5) = VAL(SG. REPLY$): RETURN
23626 IF SG.BTAB%>2 THEN GOTO 24264
23627 GOSUB 23078 SG.BTAB%=1 THEN GOTO 23825 'PN$ (2)
23628 IF SG.BTAB%>2 THEN GOTO 24264
23629 GOSUB 23084 SG.BTAB%=1 THEN GOTO 23827 'QY (2)
23630 IF SG.BTAB%>2 THEN GOTO 24264
23631 GOSUB 23090 SG.BTAB%=1 THEN GOTO 23829 'SR (2)
23632 IF SG.BTAB%>2 THEN GOTO 24264
23633 GOSUB 23096 SG.BTAB%=1 THEN GOTO 23831 'PR (2)
23634 IF SG.BTAB%>2 THEN GOTO 24264
23635 GOSUB 23102 SG.BTAB%=1 THEN GOTO 23833 'CP (2)
23636 IF SG.BTAB%>2 THEN GOTO 24264
23637 GOSUB 23108 SG.BTAB%=1 THEN GOTO 23835 'CH (2)
23638 IF SG.BTAB%>2 THEN GOTO 24264
23639 GOSUB 23114 SG.BTAB%=1 THEN GOTO 23837 'LT (2)
23640 IF SG.BTAB%>2 THEN GOTO 24264
23641 GOSUB 23120 SG.BTAB%=1 THEN GOTO 23839 'IT (3)
23642 IF SG.BTAB%>2 THEN GOTO 24264
23643 GOSUB 23126 SG.BTAB%=1 THEN GOTO 23841 'PN$ (3)
23644 IF SG.BTAB%>2 THEN GOTO 24264
23645 GOSUB 23132 SG.BTAB%=1 THEN GOTO 23843 'QY (3)
23646 IF SG.BTAB%>2 THEN GOTO 24264
23647 GOSUB 23138 SG.BTAB%=1 THEN GOTO 23845 'SR (3)
23648 IF SG.BTAB%>2 THEN GOTO 24264
23649 GOSUB 23144 SG.BTAB%=1 THEN GOTO 23847 'PR (3)
23650 IF SG.BTAB%>2 THEN GOTO 24264
23651 GOSUB 23150 SG.BTAB%=1 THEN GOTO 23849 'CP (3)
23652 IF SG.BTAB%>2 THEN GOTO 24264
23653 GOSUB 23156 SG.BTAB%=1 THEN GOTO 23851 'CH (3)
23654 IF SG.BTAB%>2 THEN GOTO 24264
23655 GOSUB 23162 SG.BTAB%=1 THEN GOTO 23853 'LT (3)
23656 IF SG.BTAB%>2 THEN GOTO 24264
23657 GOSUB 23168 SG.BTAB%=1 THEN GOTO 23855 'IT (4)
23658 IF SG.BTAB%>2 THEN GOTO 24264
23659 GOSUB 23174 SG.BTAB%=1 THEN GOTO 23857 'PN$ (4)
23660 IF SG.BTAB%>2 THEN GOTO 24264
23661 GOSUB 23180 SG.BTAB%=1 THEN GOTO 23859 'QY (4)
23662 IF SG.BTAB%>2 THEN GOTO 24264
23663 GOSUB 23186 SG.BTAB%=1 THEN GOTO 23861 'SR (4)
23664 IF SG.BTAB%>2 THEN GOTO 24264
23665 GOSUB 23192 SG.BTAB%=1 THEN GOTO 23863 'PR (4)
23666 IF SG.BTAB%>2 THEN GOTO 24264
23667 GOSUB 23198 SG.BTAB%=1 THEN GOTO 23865 'CP (4)
23668 IF SG.BTAB%>2 THEN GOTO 24264
23669 GOSUB 23204 SG.BTAB%=1 THEN GOTO 23867 'CH (4)
23670 IF SG.BTAB%>2 THEN GOTO 24264
23671 GOSUB 23210 SG.BTAB%=1 THEN GOTO 23869 'LT (4)
23672 IF SG.BTAB%>2 THEN GOTO 24264
23673 GOSUB 23216 SG.BTAB%=1 THEN GOTO 23871 'IT (5)
23674 IF SG.BTAB%>2 THEN GOTO 24264
23675 GOSUB 23222 SG.BTAB%=1 THEN GOTO 23873 'PN$ (5)
23676 IF SG.BTAB%>2 THEN GOTO 24264
23677 GOSUB 23228 SG.BTAB%=1 THEN GOTO 23875 'QY (5)
23678 IF SG.BTAB%>2 THEN GOTO 24264
23679 GOSUB 23234 SG.BTAB%=1 THEN GOTO 23877 'SR (5)
23680 IF SG.BTAB%>2 THEN GOTO 24264
23681 GOSUB 23240 SG.BTAB%=1 THEN GOTO 23879 'PR (5)
23682 IF SG.BTAB%>2 THEN GOTO 24264
23683 GOSUB 23246 SG.BTAB%=1 THEN GOTO 23881 'CP (5)
23684 IF SG.BTAB%>2 THEN GOTO 24264
23685 GOSUB 23252 SG.BTAB%=1 THEN GOTO 23883 'CH (5)
23686 IF SG.BTAB%>2 THEN GOTO 24264
23687 GOSUB 23258 SG.BTAB%=1 THEN GOTO 23885 'LT (5)
23688 IF SG.BTAB%>2 THEN GOTO 24264
23689 GOSUB 23264 SG.BTAB%=1 THEN GOTO 23887 'IT (6)
23690 IF SG.BTAB%>2 THEN GOTO 24264
23691 GOSUB 23270 SG.BTAB%=1 THEN GOTO 23889 'PN$ (6)
23692 IF SG.BTAB%>2 THEN GOTO 24264
23693 GOSUB 23276 SG.BTAB%=1 THEN GOTO 23891 'QY (6)
23694 IF SG.BTAB%>2 THEN GOTO 24264
23695 GOSUB 23282 SG.BTAB%=1 THEN GOTO 23893 'SR (6)
23696 IF SG.BTAB%>2 THEN GOTO 24264
23697 GOSUB 23288 SG.BTAB%=1 THEN GOTO 23895 'PR (6)
23698 IF SG.BTAB%>2 THEN GOTO 24264
23699 GOSUB 23294 SG.BTAB%=1 THEN GOTO 23897 'CP (6)
23700 IF SG.BTAB%>2 THEN GOTO 24264
24159 LOCATE 10+Q%,5:PRINT USING "\\I$1Q%\"
24161 LOCATE 10+Q%,22:PRINT USING \""\";PR(Q%)
24163 LOCATE 10+Q%,21:PRINT USING "******%IY(Q%)
24165 LOCATE 10+Q%,40:PRINT USING "******%LIY(Q%)
24167 LOCATE 10+Q%,50:PRINT USING "******%PIY(Q%)
24169 LOCATE 10+Q%,59:PRINT USING "******%CIY(Q%)
24171 LOCATE 10+Q%,68:PRINT USING "******%CHI(Q%)
24173 LOCATE 10+Q%,76:PRINT USING "******%LTI(Q%)
24175 NEXT
24207 LOCATE 24,56:COLOR 15,1:PRINT USING "I";SCR$
24209 RETURN
24210 GOSUB 24216
24212 GOSUB 24013
24214 RETURN
24215 LOCATE 25,1:COLOR 0,PRINT "$;
24216 COLOR 0;CLS:GOSUB 1462
24217 COLOR 2,0
24218 COLOR 3,0:LOCATE 2,1:PRINT "LIST STOCKABLE ITEMS"
24219 "SO THAT SPARE PARTS REQUIREMENTS MAY BE CALCULATED"
24220 COLOR 3,0:LOCATE 4,10:PRINT "When needed, press the"
24221 "F9 key to advance to bottom"
24222 COLOR 3,0:LOCATE 4,61:PRINT "of screen."
24224 COLOR 2,0:LOCATE 6,1:PRINT "Node name:";
24226 LOCATE 7,1:PRINT "Quantity"
24227 LOCATE 8,1:PRINT "Stockable item Part#"
24228 LOCATE 10+Q%,11:PRINT USING "SS. $";Q%
24230 LOCATE 10+Q%,2:PRINT USING "$ Q parts ($ per part)
24232 COLOR 2,0:LOCATE 9,70:PRINT "$ (per part)"
24234 FOR Q% = 1 TO 10
24236 LOCATE 10+Q%,1:PRINT USING "SS. "$;
24248 LOCATE 10+Q%,1:PRINT USING "SS. "$;
24250 COLOR 3,0:LOCATE 24,34:PRINT "Enter F to continue"
24260 COLOR 15,1:LOCATE 24,56:PRINT "$"
24262 COLOR 2,0:RETURN
24264 IF SG.BTAB% < 5 THEN RETURN ELSE GOTO 24001
PROGRAM LISTING FOR "EXISTING"

GOSUB SCREEN SUBROUTINE
GROUP ANY EXISTING END ITEMS INTO STREAMS

EXPLANATION AND FIRST STREAM

REG%=2:GOSUB 19000
 IF SCR$ = "R" THEN 11
AGE%= 1 THEN 97

GOSUB SCREEN SUBROUTINE
GROUP ANY EXISTING END ITEMS INTO STREAMS

SECOND AND THIRD STREAMS

REG%=2:GOSUB 19350
 IF SCR$ = "R" THEN 11
AGE% <= 3 THEN 97

GOSUB SCREEN SUBROUTINE
GROUP ANY EXISTING END ITEMS INTO STREAMS

FOURTH AND FIFTH STREAMS

REG%=2:GOSUB 19900
 IF SCR$ = "R" THEN 40

INITIALIZE VARIABLES
V%= 2
 FOR N%= 1 TO 5
   KKEY%(V%) = N%; TTIME%(V%) = X0%(N%); V% = V% + 1
 NEXT N%
V%= 2
 FOR N%= 2 TO 26
   IF IP%(N%) = 0 THEN 190
   IP%(V%) = IP%(N%); TTIME%(V%) = TTIME%(N%)
   KKEY%(V%) = KKEY%(N%); RRA%(V%) = RRA%(KKEY%(N%))
   ST%(V%) = ST%(N%)
   V% = V% + 1
 NEXT N%
NS% = V%
 IF IP%(1) = 0 THEN 210

CHAIN BACK TO PROGRAM "MAIN"
BEGIN CALCULATIONS

CHAIN "MAIN",200,ALL

INITIALIZE VARIABLES

FOR N%= 2 TO NS%-1
   IP%(N%-1) = IP%(N%); TTIME%(N%-1) = TTIME%(N%)
   KKEY%(N%-1) = KKEY%(N%); RRA%(N%-1) = RRA%(N%)
   ST%(N%-1) = ST%(N%)
 NEXT N%
GOTO 200

END OF MAIN PROGRAM (EXISTING)
SCREEN SUBROUTINE DRIVER

note: subroutine not listed - See screen subroutine driver listing in lines 700 - 1486 in program "INTRO"

SCREEN SUBROUTINE
INPUT DATA FOR FIRST EXISTING STREAM

19000 ON REQ% GOSUB 19268 , 19262 , 19222 , 19132 , 19214 , 19174 , 19218
19002 RETURN
19018 SG.VV%AGE%:SG.MSK%="###":GOSUB 1471
19020 SG.ROW%=11:SG.COL%=60:SG.LNG%=3:COLOR 15,1 :GOSUB 770
19022 AGE%=VAL(SG.REPLY$):RETURN
19024 SG.VV%X0%(1):SG.MSK%="###":GOSUB 1471
19026 SG.ROW%=14:SG.COL%=58:SG.LNG%=5:COLOR 15,1 :GOSUB 770
19028 X0%(1)=VAL(SG.REPLY$):RETURN
19029 SG.VV%+/+=1:SG.COL%=72:SG.LNG%=5:COLOR 15,1 :GOSUB 770
19030 +/+=1=VAL(SG.REPLY$):RETURN
19032 SG.ROW%=16:SG.COL%=58:SG.LNG%=5:COLOR 15,1 :GOSUB 770
19034 +/+=1=VAL(SG.REPLY$):RETURN
19035 SG.VV%IP%(1):SG.MSK%="###":GOSUB 1471
19036 SG.ROW%=18:SG.COL%=72:SG.LNG%=5:COLOR 15,1 :GOSUB 770
19038 IP%(1)=VAL(SG.REPLY$):RETURN
19040 SG.VV%IP%(3):SG.MSK%="###":GOSUB 1471
19042 SG.ROW%=19:SG.COL%=72:SG.LNG%=5:COLOR 15,1 :GOSUB 770
19044 IP%(3)=VAL(SG.REPLY$):RETURN
19046 SG.VV%IP%(4):SG.MSK%="###":GOSUB 1471
19048 SG.ROW%=20:SG.COL%=72:SG.LNG%=5:COLOR 15,1 :GOSUB 770
19050 IP%(4)=VAL(SG.REPLY$):RETURN
19052 IP%(4)=VAL(SG.REPLY$):RETURN
19056 SG.VV%IP%(5):SG.MSK%="###":GOSUB 1471
19058 SG.ROW%=21:SG.COL%=72:SG.LNG%=5:COLOR 15,1 :GOSUB 770
19060 IP%(5)=VAL(SG.REPLY$):RETURN
19062 IP%(5)=VAL(SG.REPLY$):RETURN
19064 SG.VV%IP%(6):SG.MSK%="###":GOSUB 1471
19066 SG.ROW%=22:SG.COL%=72:SG.LNG%=5:COLOR 15,1 :GOSUB 770
19068 IP%(6)=VAL(SG.REPLY$):RETURN
19070 IP%(6)=VAL(SG.REPLY$):RETURN
19072 SG.DF%=SCR$
19074 SG.ROW%=24:SG.COL%=74:SG.LNG%=1
19076 COLOR 15,1 :GOSUB 775
19078 SCR%=SG.REPLY$:RETURN
19100 SG.VV%IP%(1):SG.MSK%="###":GOSUB 1471
19101 SG.ROW%=19:SG.COL%=72:SG.LNG%=5:COLOR 15,1 :GOSUB 770
19103 IP%(1)=VAL(SG.REPLY$):RETURN
19105 IF SG.BTAB%=1 AND NO.ENVIR%=1 THEN GOTO 19185
19107 IF SG.BTAB%=1 AND NO.ENVIR%=2 THEN GOTO 19191
19109 IF SG.BTAB%=1 AND NO.ENVIR%=3 THEN GOTO 19203
19111 IF SG.BTAB%=1 AND NO.ENVIR%=4 THEN GOTO 19211
19113 IF SG.BTAB%=1 AND NO.ENVIR%=5 THEN GOTO 19209
19115 IF SG.BTAB%=1 THEN GOTO 19197
19117 IF SG.BTAB%=2 THEN GOTO 19200
19119 IF SG.BTAB%=2 THEN GOTO 19202
19121 IF SG.BTAB%=2 THEN GOTO 19204
19123 IF SG.BTAB%=2 THEN GOTO 19206
19125 IF SG.BTAB%=2 THEN GOTO 19208
19127 IF SG.BTAB%=2 THEN GOTO 19210
19129 IF SG.BTAB%=2 THEN GOTO 19212
19131 IF SG.BTAB%=2 THEN GOTO 19214
19133 IF SG.BTAB%=2 THEN GOTO 19216
19135 IF SG.BTAB%=2 THEN GOTO 19218
19137 RETURN
19140 GOSUB 1462
EXISTING END ITEMS DATA INPUT

should be divided into groups depending on how many they have been in operation. You will be asked to input

"total # of end items in each age group."

"Age of group 1 in periods";

"Age of group 1 in periods";

"Total # end items in age group 1";

"Divide total # end items";

"failure environments";

"following (R to go back, F to go forward)";

"Input data for second and third stream"
SCREEN SUBROUTINE
INPUT DATA FOR FOURTH AND FIFTH STREAM

note: subroutine not listed -
This screen subroutine is similar to
the subroutine in lines 19000 - 19320.
PROGRAM LISTING "DIVIDE"

INITIALIZE VARIABLES

R% = NS%; SUM% = 0; KK% = IP%(NS%)
FOR N% = 1 TO NO.ENVIRX
SUMSTREAM(KKEY%(N%)) = SUMSTREAM(KKEY%(N%)) + SP2%(N%)
NEXT N%

GOSUB SCREEN SUBROUTINE
INPUT NUMBER OF END ITEMS TO BE PLACED IN EACH ENVIRONMENT

INITIALIZE VARIABLES

V% = R%; VT% = 1
FOR N% = RX TO R% + 4
IF IP%(N%) = 0 THEN 516
IP%(V%) = IP%(N%); KKEY%(V%) = VT%; V% = V% + 1
VT% = VT% + 1
NEXT N%
NS% = V% - 1; V% = 0
FOR N% = RX TO NS%
TTIME%(N%) = T%; ST%(N%) = IP%(N%)
RA%(N%) = RA%(KKEY%(N%)); SUM% = SUM% + IP%(N%); V% = V% + 1
NEXT N%
IF IP%(NS%) > 0 THEN NS% = NS% + 1; D% = 1
IF SUM% = KK% THEN 650

CHECK USER'S ADDITION

CLS; COLOR 2,0; LOCATE 10,30: PRINT "Check your addition."
PRINT "The # of units assigned to failure environments does not equal the # of units procured."
COLOR 3,0; LOCATE 20,20
PRINT "press any key to review previous input"
A$ = INKEY$: A$ = "" THEN GOTO 600
NS% = R%; SUM% = 0: GOTO 500

CHAIN TO Appropriate PLACE IN PROGRAM "MAIN"

IF F% = 0 THEN CHAIN "MAIN", 630, ALL
IF F% = 1 THEN CHAIN "MAIN", 1130, ALL
IF F% = 2 THEN CHAIN "MAIN", 1180, ALL

END OF MAIN PROGRAM (DIVIDE)

SCREEN SUBROUTINE DRIVER

note: subroutine not listed -
See the screen subroutine driver in lines 700 - 1486 in program "INTRO".

25000 ON REQ% GOSUB 25364 , 25358 , 25302 , 25180,
25294 , 25238 , 25298
25002 RETURN
LOCATE 18,25:COLOR 6,0:PRINT USING "####";RA(4)
LOCATE 18,37:COLOR 6,0
PRINT USING "####";DEMAND(4)
LOCATE 18,49:COLOR 6,0
PRINT USING "####";SUMSTREAM(4)
IF NO.ENVIR%=4 THEN GOTO 25355
LOCATE 20,2:COLOR 6,0
PRINT USING "V";NO.ENVIR$15 JJ
LOCATE 20,25:COLOR 6,0:PRINT USING "ll#n"JRA(5h
LOCATE 20,37:COLOR 6,0
PRINT USING "IJ;tt#l"JDEMAND%15JJ
LOCATE 20,49:COLOR 6,0
PRINT USING "###U"JSUMSTREAM(5JJ
LOCATE 20,66:COLOR 15,1
PRINT USING "##;##" J IP%1 NS%+4 h
LOCATE 23,53:COLOR 15,1:PRINT "!
RETURN
GOSUB 25364
GOSUB 25303
RETURN
LOCATE 25,1:COLOR 1,0:PRINT " 
COLOR 2,0:CLS:GOSUB 1462
COLOR 3,0:LOCATE 2,16:PRINT "DIVIDE PROCUREMENT" "INTO FAILURE ENVIRONMENTS"
COLOR 3,0:LOCATE 4,26
PRINT "Units have just been procured."
LOCATE 6,1:PRINT "Divide this procurement"
"into failure environments:"
COLOR 2,0:LOCATE 8,2:PRINT "Retirement Demand"
"Units"
COLOR 2,0:LOCATE 8,63:PRINT "Units to be"
COLOR 2,0:LOCATE 9,27:PRINT "Age"
COLOR 2,0:LOCATE 9,45:PRINT "Presently in"
COLOR 2,0:LOCATE 10,22:PRINT "Periods"
COLOR 2,0:LOCATE 10,36:PRINT "Units"
COLOR 2,0:LOCATE 10,46:PRINT "Operation"
COLOR 2,0:LOCATE 10,64:PRINT "Environment"
FOR X%=1 TO NO.ENVIR
COLOR 15,1:LOCATE 10+X%*2,66:PRINT " 
COLOR 2,0:RETURN
IF SG.BTABX<5 THEN RETURN ELSE GOTO 25291
PROGRAM LISTING "PRINTOUT"

PRINT PERIOD BY PERIOD AVAILABILITY OF END ITEM

PRINTPERIODBYPERIODAVAILABILITYOFENDITEM

LPRINT "SIDE-LOADABLE WARPING TUG": LPRINT: LPRINT Period Support

"Combat Total System"

LPRINT "------- ------- -------": LPRINT

F52$ = "$ $ $ 

FOR NZ = 1 TO LMR

LPRINT USING F52$NZ;GAI(NZ,1);GAI(NZ,2);TOTALAVAIL(NZ)

NEXT

CLS: LOCATE 10,20

PRINT "set printer: press any key to continue"

A$ = INKEY$: IF A$ = "": THEN 36110

PRINT PERIOD BY PERIOD COST SUMMARY

PRINT "SUPPORT AREA PERIOD BY PERIOD COST SUMMARY"

LPRINT: LPRINT

LPRINT "------- ------- -------": LPRINT

F53$ = "$ $ $ 

FOR NZ = 1 TO 12

LPRINT USING F53$NZ;GCOST(NZ,1);GCOST(NZ,2);GCOST(NZ,3);GCOST(NZ,4);GCOST(NZ,5)

NEXT

CLS: LOCATE 10,20

PRINT "set printer: press any key to continue"

A$ = INKEY$: IF A$ = "": THEN 36110

PRINT PERIOD BY PERIOD COST SUMMARY

PRINT "------- ------- -------": LPRINT

F54$ = "$ $ $ 

FOR NZ = 13 TO 24

LPRINT USING F54$NZ;GCOST(NZ,1);GCOST(NZ,2);GCOST(NZ,3);GCOST(NZ,4);GCOST(NZ,5)

NEXT

CLS: LOCATE 10,20

PRINT "set printer: press any key to continue"

A$ = INKEY$: IF A$ = "": THEN 36110

PRINT PERIOD BY PERIOD COST SUMMARY

PRINT "------- ------- -------": LPRINT

LPRINT: LPRINT: LPRINT

"Procurement Units" "Cost/Unit"

LPRINT: LPRINT: LPRINT

"Procurement Units" "Cost/Unit"

LPRINT: LPRINT: LPRINT

"Procurement Units" "Cost/Unit"

LPRINT: LPRINT: LPRINT

"Procurement Units" "Cost/Unit"

LPRINT: LPRINT: LPRINT

"Procurement Units" "Cost/Unit"
36600 FOR N% = 13 TO 24
36610 LPRINT USING F54$;1N%;PCOST(N%);GCOST(N%);61;
    GCOST(N%);7;GCOST(N%;8)
36620 NEXT
36630 CLS: LOCATE 10,20
36631 PRINT "set printer: press any key to continue"
36640 A$ = INKEY$: IF A$ = "" THEN 36640
36680 ' PRINT PERIOD BY PERIOD MANPOWER REQUIREMENTS
36681 ' 36682 ' 36683 ' 36684 ' 36685 ' 36686 ' 36687 ' 36688 ' 36689 ' 36690 ' 36691 ' 36692 ' 36693 ' 36694 ' 36695 ' 36696 ' 36697 ' 36698 ' 36699 ' 36700 ' 36701 ' 36702 ' 36703 ' 36704 ' 36705 ' 36706 ' 36707 ' 36708 ' 36709 ' 36710 ' 36711 ' 36712 ' 36713 ' 36714 ' 36715 ' 36716 ' 36717 ' 36718 ' 36719 ' 36720 ' 36721 ' 36722 ' 36723 ' 36724 ' 36725 ' 36726 ' 36727 ' 36728 ' 36729 ' 36730 ' 36731 ' 36732 ' 36733 ' 36734 ' 36735 ' 36736 ' 36737 ' 36738 ' 36739 ' 36740 ' 36741 ' 36742 ' 36743 ' 36744 ' 36745 ' 36746 ' 36747 ' 36748 ' 36749 ' 36750 ' 36751 ' 36752 ' 36753 ' 36754 ' 36755 ' 36756 ' 36757 ' 36758 ' 36759 ' 36760 ' 36761 ' 36762 ' 36763 ' 36764 ' 36765 ' 36766 ' 36767 ' 36768 ' 36769 ' 36770 ' 36771 ' 36772 ' 36773 ' 36774 ' 36775 ' 36776 ' 36777 ' 36778 ' 36779 ' 36780 ' 36781 ' 36782 ' 36783 ' 36784 ' 36785 ' 36786 ' 36787 ' 36788 ' 36789 ' 36790 ' 36791 ' 36792 ' 36793 ' 36794 ' 36795 ' 36796 ' 36797 ' 36798 ' 36799 ' 36800 CHAIN "INPUT2",90,ALL
APPENDIX 3.

Operator's Guide
OPERATOR'S GUIDE FOR

MRPM

MAINTENANCE REQUIREMENTS PLANNING MODEL

for the IBM-PC

Developed by:
Department of Industrial Engineering and Operations Research
Virginia Tech
Blacksburg, Virginia 24060
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Section 7: Output Summaries......................page 321.
MRPM is a user friendly computer software package designed for use by Logistics Planners. MRPM will assist in the evaluation of maintenance requirements generated by repairable item populations. The population may be operating under conditions where steady-state or nonsteady-state maintenance requirements are being generated.

This operator's guide will illustrate all introductory, input, and output screens that the user of the model may deal with. Key selections available for use by the user of the model are detailed. The "Options" section of this guide gives further information on options that the user may select when using the model. Finally, the model Output Summaries are described.
Section 2: GETTING STARTED

MRPM is programmed in Microsoft Advanced Basic (Basica), and is compatible with an IBM-PC with a color monitor. A PC with two 5 1/4" disk drives is required.

Follow these steps to get MRPM running:

1) "Boot" your PC with DOS 2.1 (only versions of DOS that will support Basica may be used)

2) Place the MRPM diskette in disk drive b: (right hand or bottom disk drive).

3) Place the DATA diskette in disk drive a: (left hand or top disk drive).

4) If the PC has been "booted" there should be an "A>" showing on the CRT screen. Beside "A>", type BASICA and <return>.

5) When the Basica prompt "OK" appears, type LOAD "B:MAIN" and <return>.

6) Type RUN and <return>.

MRPM is now running. The first screen that you will see is screen 1, described in the next section.
Section 3: INTRODUCTORY SCREENS

There are 6 introductory screens included in MRPM. The screens are intended to give the user of the model an overview of the terminology and concepts employed by MRPM. The 6 screens are shown, beginning with Screen 1 on this page, and should be self explanatory. Key selection available for use with the introductory screens is detailed on the next page.

Enter F to go forward to the next screen __

INTRO SCREEN 1

MULTI - STREAM CONCEPT

<table>
<thead>
<tr>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGE3</td>
<td>.1a.1b</td>
<td>.2a.2b</td>
<td>.3a.3b</td>
<td></td>
</tr>
<tr>
<td>AGE2</td>
<td>.1a.1b</td>
<td>.2a.2b</td>
<td>.3a.3b</td>
<td>.4a.4b</td>
</tr>
<tr>
<td>AGE1</td>
<td>1a 1b</td>
<td>2a 2b</td>
<td>3a 3b</td>
<td>4a 4b</td>
</tr>
</tbody>
</table>

T1,T2,...... = time period   AGE1,AGE2,.... = age of end items
1a 1b,...... = end items of the same age, operating in failure environments A and B
1a.1a.1a..... = a stream (A stream is no more when either all end items have failed or all end items are retired.)

Enter one of the following (R to go back one screen, F to go forward) __

INTRO SCREEN 2
The repairable items being evaluated by this logistics model are referred to as end items. Each end item is broken into repairable or replaceable components and then into subcomponents and so on until a spare part level is reached. This "breakdown" produces a maintenance tree. See the next screen for a sample maintenance tree.

Maintenance Tree Terminology:
- node - each component on the tree represents a node
- bottom of tree node - this is the node where failure and repair data is known
- stockable items - parts needed to repair the component listed at bottom of the tree node
- repair level - maintenance facility which must perform the repair

Enter one of the following (R to go back one screen, F to go forward) ___

---

Key Selection for all INTRO Screens:
* R <return> ........display previous screen
* F <return> ........display next screen
The previous screen was a partial maintenance tree for an automobile with the following explanations:

- Alternator and ignition were bottom of the tree nodes.
- Alternator, brushes, and bolts were stockable items.
- MTTR (mean time to repair).
- MTBF (mean time between failures).
- RL (repair level).

The next screen shows the maintenance tree limitations for this model:

- Max. # nodes = 126
- Max. levels of indenture = 5

Enter one of the following (R to go back one screen, F to go forward):

---

INTRO SCREEN 5

---

g graphical depiction of maintenance tree (not shown here)

---

Enter one of the following (R to go back one screen, F to go forward):
Section 4: INPUT SCREENS

The input screens are the screens of MRPM designed to accept input from the model user. The input may be data concerning the population being evaluated or model option choices.

It is important that the model user follow the directions displayed on each input screen.

Each input screen is illustrated in this section. Key selection for each screen is also detailed.

MRPM displays the screens in the same order that they are displayed in this chapter.
DATA CHOICE

1...........Work Example
2...........Save Data
3...........Continue - All New Inputs
4...........Review Intro Screens
5...........End Program

Enter 1, 2, 3, 4, or 5 >

INPUT SCREEN 1

PRINTER CHOICE

1...........Printer Listings of all Model Outputs
2...........Printer Listings of Summaries Only - Viewing of Screen Output Allowed
3...........Printer Listings of Summaries Only - Viewing of Screen Output Not Allowed

Enter 1, 2, or 3 > ___

INPUT SCREEN 2

See Section 6 of this guide for further explanation of the model options for input screens 1 and 2.

Key Selection for input screens 1 and 2:

* type the number of your selection and <return>. 
This model will produce period by period maintenance requirements.

Will a period be defined in days, weeks, months, or years? 

How long will each time period be (of dys, wks, mths, yrs)? 

How many periods should the model run? 

Operating environment information:

It is possible for units of the same age to have different failure rates due to the respective environments in which the units operate.

In how many different failure environments will your population of repairable units operate? (limit of 4 environments)

Enter one of the following (R to go back one screen, F to go forward) 

Input data may be entered only in the areas marked as blank lines on the above illustration. On the color monitor of your IBM-PC, the input areas will appear as bright blue boxes. The cursor may not be moved to any point outside these boxes.

Key Selection for Input Screen 3:

* R <return> ............display previous screen
* F <return> ............display next screen
* <F9> ............move cursor to last input area on screen
* <F10> ............execute command contained in last input area
* <pg up> ............move to previous input area
* <pg dn> ............move to next input area
* <enter> ............move to next input area

note: Always type <return> after data is input in an input area.

This set of key selections will be referred to as Key Selection A as it will apply to other input screens.
The following cost information will be required in order to calculate the costs involved with implementing the logistics policies you choose:

1) First cost (of an end item) $______

2) Salvage value (of an end item) $______

3) Procurement costs (i.e., the administrative costs incurred each time a procurement of end items occurs) $______

4) Repair cost per day (include labor, transportation, and overhead costs that are incurred, on the average, each time an end item is serviced by a repair facility) $______/day

5) Shortage cost per day (the cost incurred when there are not enough end items in operation to satisfy the demand) $______/day

6) Interest rate per period (time value of money) ______%  

Enter one of the following (r to go back one screen, f to go forward) __

CHOICE OF MODEL MODE

A.....The model will be used to build and evaluate a proposed population.  
B.....The model will be used to evaluate a population in which some units are already in operation.

Enter either A or B ______

CHOICE OF SPARE PARTS AND WAREHOUSE REQUIREMENTS OUTPUT

1.....Compute spare parts and warehouse requirements

2.....Compute spare parts and warehouse requirements and replenish inventory using EOQ

3.....Do not compute spare parts and warehouse requirements

Enter either 1, 2, or 3 ______

NUMBER OF REPAIR LEVELS IN MAINTENANCE SYSTEM

Enter # of repair levels (maximum 5) ______

Enter one of the following (r to go back one screen, f to go forward) __

See Section 6 of this guide for a discussion of the Model Mode and Spare Parts and Warehouse options.

Key Selection for Input Screens 4 and 5:

* use Key Selection A
If the Data Choice input by the model user on Input Screen 1 was 1 or 2 then the next Input Screen displayed will be Input Screen 6a shown below. This Input Screen will be shown in lieu of Input Screens 6 and 7.1 - 7.3 which are described on the following pages.

Input Screen 6a summarizes the "bottom of the tree" node data that is already in MRPM's memory whether the data remains from a previous model run or whether the data is the data from the example problem that the model can run. The user may make changes to the data by typing over the displayed data on Input Screen 6a.

```
Node Name | Failure Curve | MTBF | MTTR | RL
$ | $ | $ | $ | $
$ | $ | $ | $ | $
... | ... | ... | ... | ...

Enter F to go forward
```

INPUT SCREEN 6a

Key Selection for Input Screen 6a:
* Use Key Selection A. The one exception is that the R command may not be used. It is not possible to return to a previous screen.
LIBRARY OF FAILURE CURVES

1) Uniform  2) Exponential  3) Exp. Increase  4) Normal  5) Bathtub

The above curves are cumulative distributions of failure rate probabilities. To interpret the curves read the x axis as time and the y axis as the probability of failure. Therefore, the curves represent the probability of failure of an item during that item's life cycle.

If one of these curves appears to represent the failure characteristics of the item that you are evaluating, enter either 1, 2, 3, 4, or 5 on the next screen when you are asked for the failure rate curve shape. The model will compute period by period failure probabilities automatically. If you have period by period failure data available for certain items, enter 6 for failure rate curve shape and 0 for MTBF. Input failure data later.

Enter one of the following (r to go back one screen, f to go forward) __

INPUT SCREEN 6

Input screen 6 gives a description of the user's choices in describing the failure rate of each of the "bottom of the tree" node components that make up the end item.

Before proceeding through this section of input curves, the model user should construct a maintenance tree and identify each node of the tree by component name. Failure data must be gathered for each "bottom of the tree node" so that it may be input on the next series of screens.

Input screen 7.1 lists the input data that will be required for each "bottom of the tree" node. More detail on the structure of the maintenance tree is contained in the Introductory Screens. (See Section 3 of this guide.)

Key Selection for Input Screen 6:

R <return> ......display previous screen
F <return> ......display next screen

note: When you enter F and move to the next screen, you will not be able to further access Input Screens 1-6 during this model run.
LIBRARY OF FAILURE CURVES

1) Uniform  2) Exponential  3) Exp. Increase  4) Normal  5) Bathtub

INPUT MAINTENANCE TREE DATA BY FAILURE ENVIRONMENT

Enter a 1 or 2 word description of the operating environment for units operating in failure environment # n > 

You will be asked to enter known failure rate information about the item being evaluated. The information will be entered by maintenance tree node.

You must input the following information when prompted:

Node #  Node Name  Failure Rate Curve Shape
Mean Time Between Failures  Mean Time to Repair  Repair Level

press any key to continue

INPUT SCREEN 7.1

LIBRARY OF FAILURE CURVES

1) Uniform  2) Exponential  3) Exp. Increase  4) Normal  5) Bathtub

Node 6 represents the chance of fatal failure of the end item. Data for this node must be provided - input as prompted, then continue with the input of information for other bottom of the tree nodes.

Node# 6  Fatal Failure  Failure rate curve shape > __
MTBF > ____/per.unit  MTTR and Repair Level not applicable

Node# >  Node Name >  Failure rate curve shape > __
MTBF > ____/p.u.  MTTR > ____/p.u.  Repair Level > __

INPUT SCREEN 7.2

Key Selection for Input Screens 7.1 and 7.2:

* type in data and <return>
* 0 <return> .............If a zero is entered as the value for "Node #" the model will move to Input Screen 7.3.

note: If an entry error is made for any "bottom of the tree" node, retype the node # beside "Node #" and <return>. Then reenter the Node Name, Failure rate curve shape, MTBF, MTTR, and Repair Level for that node.
FAILURE ENVIRONMENT # n DATA INPUT (continued)

How many periods before end items are retired from operation? ___

What is the book value of an end item at retirement? $___

What is the demand for units operating in this environment? ___

When you press return, data input for the next failure environment will begin if there is another failure environment. Otherwise, you will advance to the next data input screen.

Press return to continue.

INPUT SCREEN 7.3

Key Selection for Input Screen 7.3:

* <pg up> .....move to previous input area
* <pg dn> .....move to next input area
* <F9> <return> .....move to next input screen
* <F10> .....move to next input screen

note: <return> after each input.

If the model user specified that the population of repairable items is operating in more than one environment, then the model will loop through Input Screens 7.1 - 7.3 until input has been received for each environment.

Each end item must have an identically structured maintenance tree, so on subsequent loops through Input Screens 7.1 - 7.3, the model will provide the node #, the node name, and the repair level. The user of the model inputs the Failure curve shape, MTBF, and MTTR for each "bottom of the tree" node.
PROCUREMENT POLICY SELECTION

This will be the policy that you wish to follow in procuring end items.

1. Continuous Uniform Procurement
2. Uniform Procurement Until Upper Limit is Reached
3. One Initial Block Procurement
4. Block Procurement with Replenishment as Units Fail Fatally
5. Continuous Increasing Procurement Amounts
6. Increasing Procurement Until Upper Limit is Reached
7. Continuous Decreasing Procurement Amounts
8. Decreasing Procurement Until Upper Limit is Reached
9. Other

Enter either 1,2,3,4,5,6,7,8, or 9 ______
Enter F to go forward ______

INPUT SCREEN 8

Key Selection for Input Screens 8 and 9.1 - 9.9:

* Use Key Selection A.

Depending on the procurement policy selected, one of the Input Screens 9.1 - 9.9 will be displayed following Input Screen 8. If you first select a procurement policy and move to the appropriate Input Screen 9.i and then decide to select a different procurement policy, type R <return> to return to Input Screen 8. Then select a different procurement policy.
CONTINUOUS UNIFORM PROCUREMENT

• End Items to be Procured per Procurement

• Periods Between Procurements

• End Items in the Initial Procurement

Enter one of the following (R to go back one screen, F to go forward)

INPUT SCREEN 9.1

UNIFORM PROCUREMENT UNTIL UPPER LIMIT IS REACHED

1. Maintain Population at Upper Limit
2. Cease Procuring Completely When Upper Limit is Reached and Let Population Die Out

Enter either 1 or 2

Upper Population Limit
• End Items to be Procured per Procurement
• Periods Between Procurements
• End Items in Initial Procurement

Enter one of the following (R to go back one screen, F to go forward)

INPUT SCREEN 9.2
ONE INITIAL BLOCK PROCUREMENT

$ End Items in the Initial Block Procurement

Enter one of the following (R to go back one screen, F to go forward) _

INPUT SCREEN 9.3

BLOCK PROCUREMENT WITH REPLENISHMENT AS UNITS FAIL FATALLY

$ Periods Between Procurements

$ End Items in Initial Procurement

Enter one of the following (R to go back one screen, F to go forward) _

INPUT SCREEN 9.4
<table>
<thead>
<tr>
<th>INCREASING PROCUREMENT AMOUNTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Increase in Procurement Amounts</td>
</tr>
<tr>
<td># Periods Between Procurements</td>
</tr>
<tr>
<td># End Items in Initial Procurement</td>
</tr>
</tbody>
</table>

Enter one of the following (R to go back one screen, F to go forward) ___

| INPUT SCREEN 9.5 |

<table>
<thead>
<tr>
<th>INCREASING PROCUREMENT UNTIL UPPER LIMIT IS REACHED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1......Maintain Population at Upper Limit</td>
</tr>
<tr>
<td>2......Cease Procuring Completely When Upper Limit is Reached and Let Population Die Out</td>
</tr>
</tbody>
</table>

Enter either 1 or 2 ____

Upper Population Limit | ____
% Increase in Procurement Amounts | ___% |
# Periods Between Procurements | ____ |
# End Items in Initial Procurement | ____ |

Enter one of the following (R to go back one screen, F to go forward) ___

| INPUT SCREEN 9.6 |
DECREASING PROCUREMENT AMOUNTS

% Decrease in Procurement Amounts

$ Periods Between Procurements

$ End Items in Initial Procurement

Enter one of the following (R to go back one screen, F to go forward) __

INPUT SCREEN 9.7

DECREASING PROCUREMENT UNTIL UPPER LIMIT IS REACHED

1.....Maintain Population at Upper Limit
2.....Cease Procuring Completely When Upper Limit is Reached and Let Population Die Out

Upper Population

% Decrease in Procurement Amounts

$ Periods Between Procurements

$ End Items in Initial Procurement

Enter one of the following (R to go back one screen, F to go forward) __

INPUT SCREEN 9.8
OTHER PROCUREMENT POLICY

Selecting this procurement policy means that you will be asked, at the end of each period, if you wish to make a procurement.

If you answer yes, then you will be allowed to input the amount of end items that you wish to procure at that time.

How many end items do you wish to procure initially? __________

Enter one of the following (R to go back one screen, F to go forward) __________

INPUT SCREEN 9.9

When all procurement policy data has been entered, the model will display a stockable items input screen.

If the model is computing only the spare parts and warehouse demand, then Input Screen 10.1 will be displayed. If the model is computing spare parts and warehouse maintenance requirements using EOQ theory, then Input Screen 10.2 will be displayed.

An input screen will be displayed for each "bottom of the tree" node. MRPM will supply the node name at the top of the screen. Be sure to list the node component as a stockable item if it is a stockable item.

If MTRP is not asked to compute any spare parts and warehouse demands, then neither Input Screen 10.1 or 10.2 will be displayed.
LIST STOCKABLE ITEMS SO THAT SPARE PARTS REQUIREMENTS MAY BE CALCULATED

When needed, press the F9 key to advance to bottom of screen.

Node name: 

<table>
<thead>
<tr>
<th>Stockable item</th>
<th>Part#</th>
<th>Quantity</th>
<th>Space Requirement (cu.ft)</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td></td>
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<tr>
<td>7.</td>
<td></td>
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<tr>
<td>8.</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>9.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Enter F to continue _

INPUT SCREEN 10.1

LIST STOCKABLE ITEMS SO THAT SPARE PARTS REQUIREMENTS MAY BE CALCULATED

When needed, press the F9 key to advance to bottom of screen.

Node name: 

<table>
<thead>
<tr>
<th>Stockable item</th>
<th>Part#</th>
<th>Quantity</th>
<th>M'house Unit Req.</th>
<th>Proc. Cost</th>
<th>Holding Cost</th>
<th>Lead Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>($parts) (cuft/part)</td>
<td>$</td>
<td>$</td>
<td>($/per)</td>
</tr>
<tr>
<td>1.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
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<tr>
<td>6.</td>
<td></td>
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</tr>
<tr>
<td>7.</td>
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<tr>
<td>8.</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Enter F to continue _

INPUT SCREEN 10.2

Key Selection for Input Screens 10.1 and 10.2:

* Use Key Selection A. There is one exception to Key Selection A. The command R may not be used as it is not possible to review a previous screen. Make sure all data is correct before leaving an input screen.
If the user specified that the repairable item population operates in more than one environment, then Input Screen 11 will be displayed next. MRPM will provide all data marked as * on the screen shown below.

This screen will be displayed again every time a procurement of end items is made and the model user will be given the opportunity to divide the newly procured end items into environments.

<table>
<thead>
<tr>
<th>DIVIDE PROCUREMENT INTO FAILURE ENVIRONMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>n units have just been procured</td>
</tr>
<tr>
<td>Divide this procurement into failure environments:</td>
</tr>
<tr>
<td>Failure Environment</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td>n</td>
</tr>
<tr>
<td>n</td>
</tr>
<tr>
<td>n</td>
</tr>
<tr>
<td>n</td>
</tr>
</tbody>
</table>

Press return to continue

INPUT SCREEN 11

Key Selection for Input Screen 11:

* Use Key Selection A. There is one exception to Key Selection A. The command R may not be used as it is not possible to review a previous screen.

If the Model Mode selected was A, i.e., the model is being used to evaluate an all new population, then the input phase of the model ends here and model operation begins. If Model Mode B is being used, then Input Screens 12.1 - 12.3 will be displayed.
EXISTING END ITEMS DATA INPUT

Existing end items should be divided into groups depending on how many periods these end items have been in operation. You will be asked to input the age of the end items and the total end items in each age group.

You will then divide the end items in each age group into different operating environments where applicable.

How many age groups of existing end items do you have? ______

Age of group 1 in periods ______

Total end items in age group 1 ______

Divide total # end items of age group 1 into failure environments ______

Enter one of the following (R to go back one screen, F to go forward) _

INPUT SCREEN 12.1

EXISTING END ITEMS DATA INPUT (cont.)

Age of group 2 in periods _____ Total # end items in age group 2 ______

Divide total # end items of age group 2 into failure environments ______

Age of group 3 in periods _____ Total # end items in age group 3 ______

Divide total # end items of age group 3 into failure environments ______

Enter one of the following (R to go back one screen, F to go forward) _

INPUT SCREEN 12.2

Key Selection for Input Screens 12.1 - 12.3:

* Use Key Selection A.

note: Using the R command while on Input Screen 12.1 will only review Input Screen 12.1. It is not possible to review any screens previous to that Input Screen.

note: Input Screen 12.3 is not shown, but is identical to Input Screen 12.2, except for the fact that it accepts input data for age groups 4 and 5. If the user does not specify that there are more than 3 age groups, then Input Screen 12.3 will not be needed and will not be displayed.
Section 5: OUTPUT SCREENS

After all data has been input by the model user, MRPM enters the operation phase. During the computations, certain output data is displayed on the screen to the model user.

If the model user chose Printer Option 2 on Input Screen 2, then MRPM will halt execution when each output screen is displayed. The model user must prompt MRPM to continue operation. If Printer Options 1 or 3 were chosen, then the only interaction between MRPM and the user, that may be required during the operation phase, is if end items are procured and must be divided into environments.

The following pages contain examples of the screen output generated by MRPM.
This Output Screen is displayed every period for each stream of end items. See Intro Screen 2 for information on streams.

This Output Screen is displayed every period for each stream of end items.
This Output Screen is displayed once at the end of each period if the model has been instructed to output only spare parts and warehouse demands.

### Output Screen 3.1

This Output Screen is displayed once at the end of each period if the model has been instructed to output only spare parts and warehouse demands.

### Output Screen 3.2

This Output Screen is displayed once at the end of each period if the model has been instructed to output spare parts and warehouse requirements using EOQ theory.
AVAILABILITY DURING TIME PERIOD $8

Availability is the probability of there being enough units in operation to meet the given demand.

<table>
<thead>
<tr>
<th>environment</th>
<th>availability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$8.5555</td>
</tr>
<tr>
<td></td>
<td>$8.5555</td>
</tr>
<tr>
<td></td>
<td>$8.5555</td>
</tr>
<tr>
<td></td>
<td>$8.5555</td>
</tr>
</tbody>
</table>

The total system availability was $8.5555

press any key to continue

OUTPUT SCREEN 4

PERIOD COST SUMMARY

<table>
<thead>
<tr>
<th>Environment</th>
<th>Capital Cost</th>
<th>Repair Cost</th>
<th>Short. Cost</th>
<th>Inven. Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$8.55</td>
<td>$8.55</td>
<td>$8.55</td>
<td>$8.55</td>
<td>$8.55</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environment</th>
<th>Units Start</th>
<th>Units End</th>
<th>Operating Cost per Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$8</td>
<td>$8</td>
<td>$8.55</td>
</tr>
</tbody>
</table>

press any key to continue

OUTPUT SCREEN 5

Both of these Output Screens are displayed once at the end of each period.
This Output Screen is displayed once at the end of the model run. After leaving this screen, the model begins to print Summaries 2-5.
Section 6: OPTIONS

Explaination of Options on Input Screen 1:

1. Work Example. MRPM will analyze a sample population in order to familiarize the user with the model input and output screens. No summaries will be printed.

2. Save Data. If a model run has just been completed and the user wishes to analyze the same population but only change a few variables, then this option may be chosen.

3. Continue - All New Inputs. The user must input all data if this option is chosen. This option must be chosen for the first model run of any population evaluation other than the example population referred to in option 1.

4. Review Intro Screens. This option may be used to review the Intro Screens.

5. End Program. Use option 5 when all model runs have been completed. When the program ends, any data left from previous runs is "forgotten" by MRPM.
Explanation of Options on Input Screen 2:

1. Printer Listings of all Model Outputs. This option will cause MRPM to operate continuously during the operation phase of the model. The only interaction between MRPM and the user will occur if end items are procured during the model run and the end items must be divided among different environments. Printer listings will be produced of all Output Screens and Output Summaries.

2. Printer Listings of Summaries Only - Viewing of Screen Output Allowed. This option will produce printer listings of only the charts shown in the Output Summary section of this operator's guide. The user of the model must be interactive with MRPM throughout the operation phase of the model, as MRPM will halt execution when each Output Screen has been displayed.

3. Printer Listings of Summaries Only - Viewing of Screen Output Not Allowed. This option will produce printer listings of only the charts shown in the Output Summary section of this operator's guide. The model will run continuously during the operation phase with no pauses during Output Screen display. The only interaction between MRPM and the user will occur if end items are procured during the model run and the end items must be divided among different environments.
Explanation of Choice of Model Mode on Input Screen 5:

A. The model will be used to build and evaluate a proposed population. The user should choose this option if there are presently no end items in operation that are to be considered by MRPM.

B. The model will be used to evaluate a population in which some units are already in operation. If MRPM will be used to evaluate future maintenance requirements for a population in which some of the end items are already in operation, then this option should be chosen. When this option is chosen, Input Screens 12.1 - 12.3 will be displayed for the user. These screens will allow the user to divide existing end items into streams.
Explanation of Spare Parts and Warehouse options on Input Screen 5:

1. . . . . Compute spare parts and warehouse requirements. If this option is chosen, the user will be asked to input stockable item data through Input Screen 10.1. MRPM will display stream spare parts and warehouse requirements through Output Screen 2 and period spare parts and warehouse requirements through Output Screen 3.1. The printer listing provided by this option will be Summary 1.1.

2. . . . . Compute spare parts and warehouse requirements and replenish inventory using EOQ. If this option is chosen, the user will be asked to input stockable item data through Input Screen 10.2. MRPM will display stream spare parts and warehouse requirements through Output Screen 2 and period spare parts and warehouse requirements through Output Screen 3.2. The printer listing provided by this option will be Summary 1.2.

3. . . . . Do not compute spare parts and warehouse requirements. If this option is chosen, MRPM will not display Input Screens 10.1 or 10.2, Output Screens 2, 3.1, or 3.2, and Summaries 1.1 or 1.2.
Section 7: OUTPUT SUMMARIES

Output summaries are produced by printer.

Summary 1.1 (or 1.2) is produced during the operation of the model, so a printer must be ready to print during the operation phase of MRPM. The other Summaries are printed at the end of a model run.

After Summary 5 has been printed, MRPM returns the user to Input Screen 1.
### SUMMARY 1.1

This Summary is printed if the model has been instructed to output only spare parts and warehouse demands.

<table>
<thead>
<tr>
<th>Node</th>
<th>Stockable Item</th>
<th>Part#</th>
<th>Spare Parts Requirements</th>
<th>Warehouse Requirements</th>
<th>Repair Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Total warehouse requirement repair level \( n = nn.nn \)

Total warehouse requirement repair level \( n = nn.nn \)

press any key to continue

### SUMMARY 1.2

This Summary is printed if the model has been instructed to output spare parts and warehouse requirements using EOQ theory.

<table>
<thead>
<tr>
<th>Node</th>
<th>Part#</th>
<th>Demand</th>
<th>W'house (cuft)</th>
<th>EOQ</th>
<th>Total Cost</th>
<th>Repair Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Total warehouse requirement repair level \( n = nn.nn \)

Total warehouse requirement repair level \( n = nn.nn \)

press any key to continue
### PERIOD POINT PROBABILITIES OF FAILURE FOR NODE 1

<table>
<thead>
<tr>
<th>Environment</th>
<th>n</th>
<th>m</th>
<th>m</th>
<th>m</th>
<th>m</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF (period)</td>
<td>n</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>m</td>
</tr>
<tr>
<td>n</td>
<td>n</td>
<td>m</td>
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</tr>
</tbody>
</table>

Press any key to continue

### SUMMARY 2

### AVAILABILITY OF END ITEM

<table>
<thead>
<tr>
<th>Period</th>
<th>n</th>
<th>m</th>
<th>m</th>
<th>m</th>
<th>m</th>
<th>m</th>
<th>Total System</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>n</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>n</td>
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</tr>
</tbody>
</table>

Press any key to continue

### SUMMARY 3
### Period by Period Manpower Requirements Summary

<table>
<thead>
<tr>
<th>Period</th>
<th>Repair Level 1 (man-days)</th>
<th>Repair Level 2 (man-days)</th>
<th>Repair Level 3 (man-days)</th>
<th>Repair Level 4 (man-days)</th>
<th>Repair Level 5 (man-days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
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</tr>
</tbody>
</table>

Press any key to continue

### Summary 4

### Cost Summary

<table>
<thead>
<tr>
<th>Period</th>
<th>Capital Cost $</th>
<th>Repair Cost $</th>
<th>Shortage Cost $</th>
<th>Inventory Cost $</th>
<th>Total Cost $</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
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<td></td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Period</th>
<th>Procurement Cost $</th>
<th># Units Start</th>
<th># Units End</th>
<th>Operating Cost/Unit $</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
</tr>
<tr>
<td></td>
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</tbody>
</table>

### Summary 5
The vita has been removed from the scanned document