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ETARA PC Version 3.3 User's Guide

Reliability, Availability, Maintainability Simulation Model

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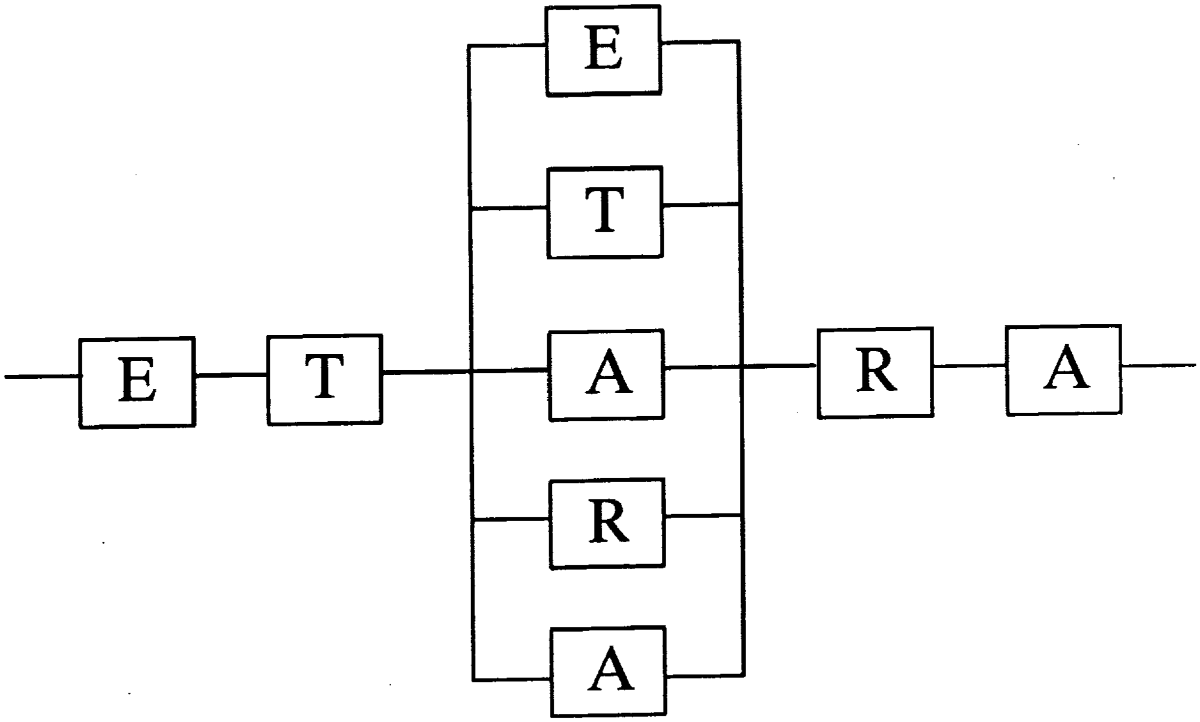

ETARA PC VERSION 3.3

USER'S GUIDE

RELIABILITY, AVAILABILITY, MAINTAINABILITY SIMULATION MODEL

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CLEVELAND, OHIO

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FOREWORD

Although written specifically for application to the Space Station Freedom Electrical Power System, the ETARA methodology and software can be applied in general to simulate Reliability, Availability, and Maintainability (RAM) characteristics of any system given a Reliability Block Diagram model of the system.

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ETARA PC VERSION 3.3

USER'S MANUAL

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1.0 Introduction

ETARA (Event Time Availability Reliability Analysis) is an interactive, menu–driven reliability, availability and maintainability (RAM) simulation program. Given a Reliability Block Diagram representation of a system, ETARA simulates the behavior of the system over a specified period of time using Monte–Carlo methods to generate block failure and repair intervals as a function of exponential and/or Weibull distributions. Availability parameters such as equivalent availability, state availability (percentage of time at a particular output state capability), continuous state duration and number of state occurrences can be calculated. Initial spares allotment and spares replenishment on a resupply cycle can be simulated. The number of block failures are tabulated both individually and by block type, as well as total downtime, repair time, and time waiting for spares. Also, maintenance man–hours per year and system reliability, with or without repair, at or above a particular output capability can be calculated over a cumulative period of time or at specific points in time.

The specific hardware and software requirements and installation instructions for ETARA are given in Appendix C on page 47.

2.0 Preparing the Input

A system can be represented by a reliability (or availability) block diagram (RBD). The RBD is a logical graphic illustration depicting the block configuration necessary for a function to be successfully accomplished. A block in the RBD can represent a component, a subsystem, or a system which performs a function that is either available or unavailable – there are no degraded modes of **block** performance. It is important to realize that the blocks do not have to be physically connected hardware in the actual system to be connected in the RBD. The criterion to remember when constructing an RBD is the block's role in contributing to an available system function.

ETARA algorithms can model systems represented by an RBD which contains a combination of series, parallel, and M–of–N parallel blocks. When two blocks, A and B, are in series, it is equivalent to saying that block A **and** block B must be available for the subsystem to be available. When two blocks are in parallel, block A **or** block B must be available for the subsystem to be available. The situation where two blocks out of three blocks in parallel are needed for the subsystem to be available is termed "M–of–N parallel", in this case M=2 and N=3. A simple combination of two or more blocks that are either in series or parallel defines a simple subsystem. Subsystems can be combined further as series or parallel combinations of other subsystems and blocks. The complete system can then be defined as a combination of subsystems and blocks.

There are no restrictions in ETARA on the number of total blocks in the RBD or on the number of blocks in a series, parallel, or M–of–N parallel subsystem. In addition, the same block can appear in more than one subsystem if such an arrangement is necessary to accurately model the system behavior. Although this is not allowed in deterministic RBD modeling, it is possible in

ETARA due to the fact that ETARA simulates failures and repairs of individual blocks and the way in which the subsystem RBD equations are solved. An example of this application is discussed in Appendix A.

In order to facilitate data entry, it is advisable to annotate a copy of the RBD, prepared within the guidelines addressed in the previous section, as follows. The blocks of the RBD should be sequentially numbered starting at one. The proper designation of the blocks is the letter "B" followed by a number – B1, B2, B3 etc. Subsystems are designated by an "S" followed by a number – S1, S2, S3 etc. The proper numbering of the subsystems is very important. The subsystems must be created from the "inside out". **A subsystem must not contain another subsystem of a higher number.** For example, if subsystem Sx contains subsystems Sy and Sz, then x must be greater than both y and z. Beginning with the innermost set of blocks, each parallel or series set of blocks are partitioned into a subsystem which then can be placed in series or parallel with other blocks and subsystems. This process is repeated until the entire system is described by one "subsystem" which contains all other subsystems and blocks. Figure 1 shows an example of an RBD properly partitioned into subsystems.

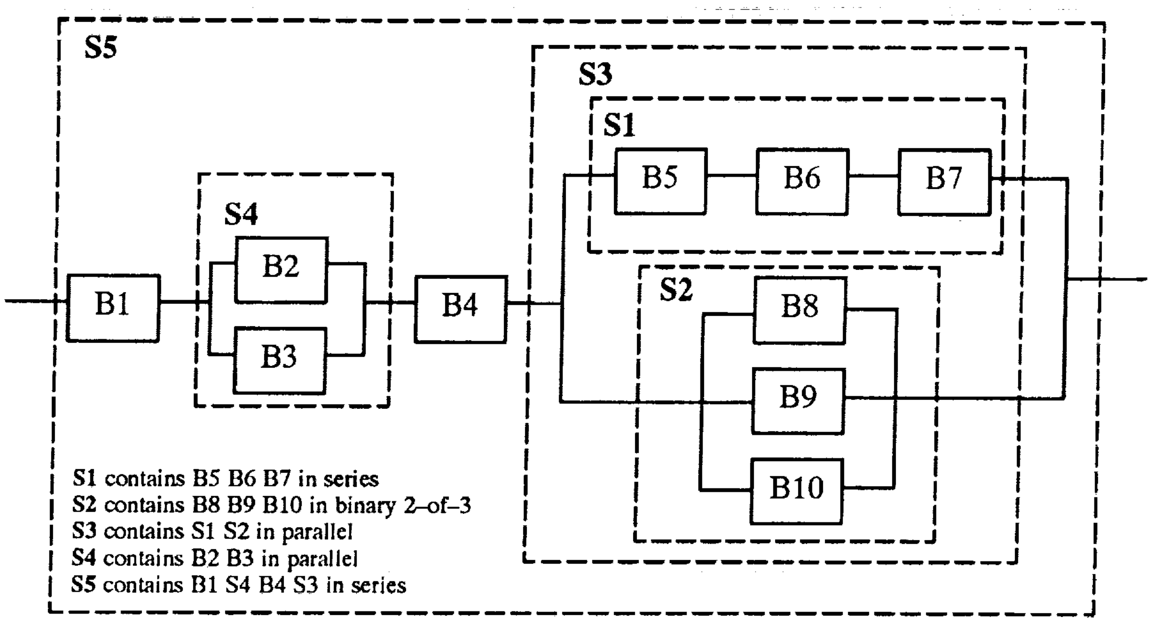


Figure 1 – Example RBD of a Simple System

The components or subsystems of the system are each represented by individual blocks in the RBD. Each block will be of a certain **type.** Each block type has associated data that differentiates it from other block types. The following data must be supplied for <u>each block type:</u>

capacity	percentage of **total** system capacity
MTBF	Mean Time Between Failures, in years, for "random" failures. Exponential Distribution = exp(–t/MTBF)
and/or	
Weibull shape factor and mean life	mean life, in years, from which the Weibull scale factor is determined. Weibull Distribution = $\exp[-(t / scale)^{shape}]$
mean time to repair, MTTR	mean repair time, in hours
number of initial local spares	spares located "on–site"
number of initial depot spares	remotely located spares

The capacity of a block is the percentage of the **total system capability** that the block either produces, conducts, or supports. For the example of an electrical power system, the percentage of total power that can be produced by, is supported by, or is conducted through a block is defined as that block's capacity. The two most important points to remember when determining a block's capacity are that a block's capacity is a **percentage of the total system capacity** and that support blocks which do not generate or contribute directly to the production of the output capability, but nevertheless are necessary in order for the system to operate, also have defined capacities. The capacities of these "support" blocks are proportional to the degradation of total system output capability when the block is unavailable. Or, as can frequently be the case, the support block can be assigned a capacity of 100% so as not to act as a bottleneck in the RBD.

ETARA uses **either, or both** of the exponential and Weibull distribution functions to generate event times for a given block. The exponential function models the useful life period where items experience a constant hazard rate, 1/MTBF (i.e. random failures). The Weibull function can be used to model a wide variety of failure distributions. Two Weibull parameters, shape and scale, are adjusted to properly form the desired distribution. Please note that the definition of "scale factor" as used in ETARA may differ from other commonly used definitions (the difference being: $scale_{ETARA} = scale^{1/shape}$). The third Weibull function parameter, the "location" factor, is used in ETARA to model the initial age or failure free period of an individual block at the beginning of the simulation and is described in detail in sections 3.2.1.1.3 and 4.2.

Within ETARA, the **mean life** of a block type is specified along with the Weibull **shape factor** from which the Weibull **scale factor** is internally calculated from the equation,

$$\text{scale factor} = \text{mean life}/\text{Gamma}(1+1/\text{shape factor})$$

where "Gamma" denotes the Gamma function. If data for both distribution functions are entered for a block type, ETARA generates time–to–failure from each function and uses the minimum of the two as the next failure event for a given block.

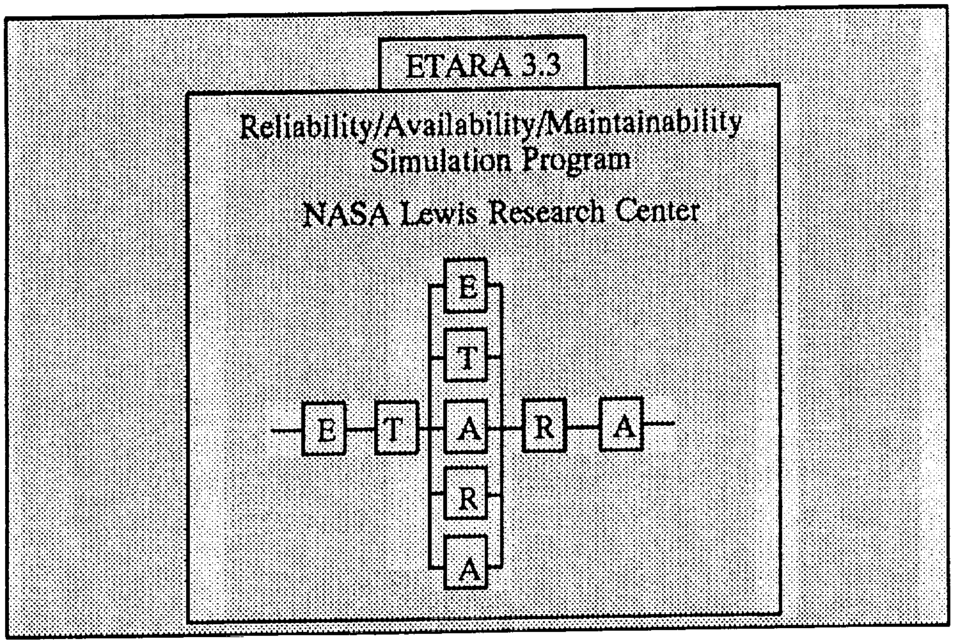
ETARA determines block down times based on the availability of local and depot spares, the MTTR, and the local and depot spares resupply interval. Local spares refers to the number of initial spares of that particular block type at the system location available for immediate replacement. Depot spares are remotely located from the system and are delivered to the system only during the local spare resupply intervals. The initial quantity of depot spares are replenished according to the depot spares replenishment interval. If a local spare is available when a block fails, ETARA uses only the block's MTTR to determine when the block will next become available. If there are no local spares but there are depot spares of the failed block's type, ETARA determines the down time to be the time remaining until the next local resupply action, plus the MTTR. If there is neither local nor depot spares of the failed block's type, ETARA determines the down time to be the time to the earliest resupply interval **after** the depot spares stock has been replenished, plus the MTTR.

3.0 The ETARA Menus

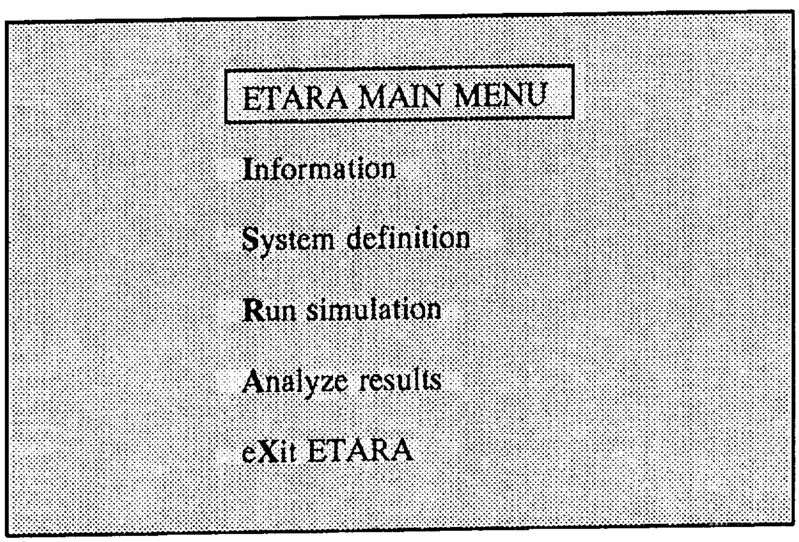
The ETARA program is executed via a hierarchical set of menus which are described in the subsections that follow. The text in the shaded area in the box represents what appears on the monitor when running ETARA. The letters in parentheses on top of the boxes represent the keystroke sequence, beginning from the main menu, which will bring up the menu shown. In ETARA, each menu listing has one **bold** letter. When making a menu choice, simply press the key of the letter desired – there is no need to press [Enter]. The [Esc] key can be pressed to "escape" out of a currently displayed menu to the previous menu. ETARA has limited built-in error detection capability in that if a wrong or inappropriate key is pressed, an error message is flashed, a beep is sounded, and the user is returned to the same or higher-level menu. On-line help screens can be accessed by pressing the [F1] key.

3.1 The ETARA MAIN MENU

On entering the ETARA program, the following introduction is briefly flashed,



followed by the ETARA Main Menu,



The ETARA main menu displays the basic steps used to approach and solve a problem. Selection **S** brings up a menu which allows the user to enter or modify the information necessary to perform a simulation of a system and manage (e.g. save, load, and delete) the system data in terms of system configuration files. Selection **R** brings up a menu which enables the user to choose an availability, reliability (with or without repair), or maintainability simulation either interactively or in batch mode. Selection **A** brings up the analytical results menu from which the results can be displayed, printed, and managed. Selection **X** is used to exit ETARA. Selection **I** displays the information contained in the Introduction to this manual, section 1.0. Remember, to make a selection simply press the key of the letter desired (without pressing [Enter]).

3.2 The SYSTEM DEFINITION Menu

Keystroke: (S)

SYSTEM DEFINITION

Enter or modify data

File management

e**X**it

The SYSTEM DEFINITION Menu allows the user to enter or modify the input necessary to perform a simulation of a system, and manage (e.g. save, load, and delete) the system data in terms of system configuration files.

RAM simulations are performed on specific "systems" or equivalently, "system configurations." For this reason, ETARA stores each system in a separate file which can be saved, deleted, reloaded and edited. A new system must be defined and saved in ETARA via the SYSTEM DEFINITION Menu. A new system configuration file must be saved using this menu before exiting ETARA or it will be lost (see section 3.5 for safeguards). Saved systems can be reloaded for use in a simulation or for editing.

Selection **X** will return the user to the ETARA MAIN MENU (3.1).

3.2.1 The DATA INPUT Menu

Keystrokes: (S) (E)

DATA INPUT

Block data, numbers, initial ages and installation times

Reliability block diagram

Parameters of the simulation

e**X**it

In order to perform a RAM simulation, each option on this menu must be selected and the appropriate input given. Selection **B** allows the user to define the RAM parameters for each block type, assign individual blocks to the various block types, and define the initial ages and points in time when blocks are installed in the system. Selection **R** allows the user to build a Reliability Block Diagram (RBD) via a full screen editor. Selection **P** allows the user to define the parameters that govern a system simulation .

As an example, input for a new system represented by the RBD depicted in figure 1 is illustrated in Appendix X.

Selection **X** will return the user to the SYSTEM DEFINITION Menu (3.2).

3.2.1.1 The BLOCK DATA INPUT Menu

Keystrokes: (S) (E) (B)

BLOCK DATA INPUT

Data by type

Numbers for each type

Ages at beginning of simulation

Installation times

e**X**it

Selection **D** is used to define the block data input to ETARA for each unique **type** of block. Selection **N** is used to identify the block **numbers** of blocks in an RBD to a unique block type. Selection **A** is used to assign **initial ages** to blocks which experience wear out. Selection **I** is used to assign **installation times** to blocks which are not initially part of a system at the beginning of a simulation. Selection **X** will return the user to the DATA INPUT Menu (3.2.1).

3.2.1.1.1 Block Data by Type

Keystrokes: (S) (E) (B) (D)

Name	Capacity (%)	MTBF, Yrs (Random)	Mean Life,Yrs (Wearout)	MTTR, hrs.	Shape Factor	Local Spares	Depot Spares
TYPE1	**100**	**5**	**5**	**1**	**10**	**0**	**9999**

After selecting the "**D**ata by type" choice from the BLOCK DATA INPUT menu, ETARA displays a table with the above listed column headings with full screen editing capability. The information given under the column headings illustrated above are default values used by ETARA. As described in 2.0 Preparing the Input, the components or subsystems of a system are each represented by individual blocks in the RBD. Each block will be of a certain type. Each unique block type has associated data that differentiates it from other block types. The block data input is defined with respect to each unique type of block. For example, an RBD may contain 100 identical blocks in series. In this case, there is only one unique type of block so that the user would enter data for only this one type of block.

The full screen editor has a vertical black column under each heading surrounded by a border. The data for each type of block is defined horizontally, with the black spaces being the "window" for the alphanumeric input. For example, the black window for the block type "Name" column is 10 spaces wide, allowing for a block name, abbreviation or acronym of 10 alphanumeric characters. The name can also contain spaces (which will appear as underscores "_" on the printout). The numeric data can be either integer or real.

To move from one window to the next, use the [Tab] key to move right and the [Shift] [Tab] keys to move left. The right and left arrow keys can also be used. The up and down arrow keys are used to move in those respective directions. If the block data input fills the screen, the [Pg Dn] key is used to page down the screen to obtain more space. The [Pg Up] key will page up the screen.

The block data editor can be used to edit existing data as well as define new data. If on entering the editor to define new block data there is already data existing in the table, the user can type over the existing information, or "mark" the data and delete it. The editor has on–line help screens which can be accessed by pressing the [F1] key. Complete instructions for using the full screen editor appear in Appendix B.

The appropriate procedure for completing the Block Data table is to begin in the upper left with a block type Name. The user can then proceed horizontally with the block capacity and other data or proceed vertically with the next block type Name. Complete data must be supplied for each block type: there can be no blanks in any of the data columns. As previously described in 2.0, the capacity of a block is the percentage of the **total system capability** that the block either produces, conducts, or supports. For the example of an electrical power system, the percentage of total power that can be produced by, is supported by, or is conducted through a block is defined as that block's capacity. It is not critical to determine the individual block capacities for blocks in an M–of–N parallel arrangement since the M–of–N subsystem capacity definition will override the individual block capacities (see 3.2.1.2.1). However, since the Capacity entry can not be left blank for these blocks, a "dummy" capacity must be defined.

The two most important points to remember when determining a block's capacity are that a block's capacity is a **percentage of the total system capacity** and that support blocks which do not generate or contribute directly to the production of the output capability, but nevertheless are necessary in order for the system to operate, also have defined capacities. The capacities of these "support" blocks can be proportional to the degradation of total system output capability when the block is unavailable. Or, as can frequently be the case, the support block can be assigned a capacity of 100% so as not to act as a bottleneck in the RBD.

ETARA uses **either, or both** of the exponential and Weibull distribution functions to generate event times for a given block. The exponential function models the useful life period where items experience a constant hazard rate, 1/MTBF (i.e. random failures). The MTBF for use in the exponential distribution function is entered in the column under the "MTBF, Yrs (Random)" heading. The Weibull function can be used to model a wide variety of failure distributions. Two Weibull parameters, shape and scale, are adjusted to properly form the desired distribution. Within ETARA, the **mean life** of a block type is specified along with the Weibull **shape factor** from which the Weibull **scale factor** is internally calculated from the equation,

scale factor = mean life/Gamma(1+1/shape factor)

where "Gamma" denotes the Gamma function.

If data for both exponential and Weibull distribution functions are entered for a block type, ETARA generates time–to–failure from each function and uses the minimum of the two as the next failure event for a given block. To use only the exponential distribution function, a "99999" is entered for Mean Life, while "99999" is entered for the MTBF if only the Weibull function is to be used.

The time–to–repair for a given block is calculated with the block's MTTR and the Weibull distribution function with the shape factor set to 3.44, approximating a normally distributed repair time. The full repair time for a block is also dependent on the logistics delay time which depends on the number and location of spares.

ETARA determines block down times based on the availability of local and depot spares, the MTTR , and the local and depot spares resupply interval (see 3.2.1.3.1). Local spares refers to the number of initial spares of that particular block type at the system location available for immediate replacement. Depot spares are remotely located from the system and are delivered to the system only during the local spare resupply intervals. The initial quantity of depot spares are replenished according to the depot spares replenishment interval. If a local spare is available when a block fails, ETARA uses only the block's MTTR to determine when the block will next become available. If there are no local spares but there are depot spares of the failed block's type, ETARA determines the down time to be the time remaining until the next local resupply action, plus the MTTR. If there is neither local nor depot spares of the failed block's type, ETARA determines the down time to be the time to the earliest resupply interval **after** the depot spares stock has been replenished, plus the MTTR. There is one further condition on the spares resupply action, the "cutoff" , described in detail in 3.2.1.3.1.

Pressing [Enter] will complete the block type definition, save the data and return the user to the BLOCK DATA INPUT menu (3.2.1.1). Pressing [Esc] will allow the user to leave the editor without saving changes.

3.2.1.1.2 Assignment of Block Numbers to Block Types

Keystrokes: (S) (E) (B) (N)

Type	Block Numbers
Type1	1 2

This selection is used to match the block numbers (i.e., the individual block identifier number, or digit) in the RBD to a unique type of block defined in the Block Data table described in the previous section. On this screen, data is also entered via a full screen editor, with identical capabilities as the Block Data editor described in the previous section – see appendix B for complete instructions. There are two headings in this editor as indicated in the example above. ETARA automatically displays the block "Type" from the type names defined in the Block Data table editor described in the previous section. In the above illustration, ETARA has displayed the default type name "Type1". For each block type listed, the user needs to define the individual block numbers which are of this type. Integer block numbers are entered which are of the block type listed on the same line to the left under the "Type" heading. Remember, a block number can be assigned to only one type of block. Numbers in a sequence can be input with the beginning number, a "dash" [–], and the ending number. For example, [1 2 4–7 9 11–25] is an appropriate response.

The [Tab] key is used to move the cursor to the right or down while the [Shift] [Tab] keys will move the cursor to the left or up. If more than one line is needed to define block numbers for a given block type, a blank line can be **inserted** by pressing the [F8] key while the cursor is positioned **one line below** the line of the block type which is to be continued. The editor will then prompt the user for the number of rows to insert. With the user response of one, a blank line will then appear above the cursor, without the block type name, in which the block number input can be continued. The Block Number editor has limited built–in error checking which will notify the user with a beep and a brief message when a block number is used more than once or is missing.

Once the block numbers have been correctly defined, the [Enter] key is pressed, the data is saved and ETARA returns to the BLOCK DATA INPUT Menu (3.2.1.1). Pressing [Esc] will allow the user to leave the editor without saving changes.

3.2.1.1.3 Block Ages at Beginning of Simulation

Keystrokes: (S) (E) (B) (A)

Age, Yrs	Block Numbers
0	1

This selection is used to assign initial ages to blocks which will either experience aging and eventual wearout, or have an initial "failure free" period. The initial block age parameter is only used in conjunction with the Weibull distribution and is equivalent to the Weibull "location" parameter.

At the beginning of the simulation, it may happen that some of the blocks which experience aging are not "brand new" and have already accumulated some "initial" age. This initial age is subtracted from the time to first failure determined with the Weibull distribution function (which is being used to model the increase in failures with time, i.e. wearout) so that the age of a block prior to the beginning of the simulation is properly accounted for.

Alternatively, a block may experience a "failure free" period at the beginning of the simulation. In this case, a negative number corresponding to the failure free period, in years, is entered. During the simulation, the defined failure free period is added to the time to first failure determined with the Weibull function so that the initial period during which the block will experience no failures related to the Weibull distribution is properly accounted for.

This screen is also a full screen editor identical to the Block Data and Block Number editors previously described. The example above shows the default values assumed by ETARA – an initial age of 0 years for block 1. If no blocks have an initial age (or failure free period), the user should press [Enter] to continue to the next menu. ETARA will internally assign an initial age of zero for every block in the system. If there are blocks which have an initial age or failure free period, the age, in years, is entered in the first column, "Age, Yrs". As indicated above, a positive entry corresponds to an initial age due to prior wear while a negative entry corresponds to an initial failure free period. The [Tab] key is used to move the cursor to the right to the "Block Numbers" column and the integer block numbers which are of that age are entered. Pressing the [Shift] and [Tab] keys together will move the cursor to the left. If more than one line is needed for a given age, simply type the same age in the next row of the first column and continue entering the block numbers. See the previous section and Appendix B for more complete instructions on the use of the full screen editor. Only blocks with an initial age or failure free period need to be identified with this selection. If a block number does not have an initial age or failure free period assigned to it by the user, ETARA assumes a value of zero. Pressing [Enter] will complete the block ages definition, save the data and return the user to the

BLOCK DATA INPUT menu (3.2.1.1). Pressing [Esc] will allow the user to leave the editor without saving changes.

3.2.1.1.4 Block Installation Times

Keystrokes: (S) (E) (B) (I)

Install. Time, yr.	Block Numbers
0	1

This option is used to assign installation times to blocks that are not initially installed, that is, not present at the beginning of the simulation. A system may be constructed in stages, with not all of the blocks operating at the start of the simulation. To account for this, an installation time, in years, may be entered. The complete block diagram should still be entered first. The non–installed blocks will be assigned a capacity of zero and will not contribute to the capacity of the system until their installation time is reached during a simulation. No time for first failure will be calculated for these blocks until they are installed. Before all blocks are installed, the system's maximum capacity will usually be less than 100%. **In ETARA, availability results are normalized to the maximum possible output capacity during a given time period.** This means that during the period when blocks are being installed, occurrence of the maximum capacity state possible, even though it could be less than the 100% ultimately possible, will be bookept under the 100% capacity state. In the availability results displays, the 100% capacity state availability includes occurrences of any state which was the maximum possibly state during a given time period.

This screen is again a full screen editor identical to the editors previously described. The example above shows the default values assumed by ETARA – an installation time of year 0 for block 1. If no blocks have a "delayed" installation time, the user should press [Enter] to continue to the next menu. ETARA will internally assign an installation time of zero for every block in the system, effectively activating the entire system at the beginning of the simulation. If there are blocks which are not initially installed, the installation time, in years, is entered in the first column, " Install. Time, yr". The [Tab] key is used to move the cursor to the right to the "Block Numbers" column and the integer block numbers which are to be installed at that time are entered. Pressing the [Shift] and [Tab] keys together will move the cursor to the left. If more than one line is needed for a given age, simply type the same installation time in the next row of the first column and continue entering the block numbers. See appendix B for more complete instructions on the use of the full screen editor. Pressing [Enter] will complete the installation time definition, save the data and return the user to the BLOCK DATA INPUT menu (3.2.1.1). Pressing [Esc] will allow the user to leave the editor without saving changes.

3.2.1.2 The RELIABILITY BLOCK DIAGRAM Menu

Keystrokes: (S) (E) (R)

RELIABILITY BLOCK DIAGRAM MENU

Enter reliability block diagram

Graphic layout display

eXit

Selection **E** is used to enter or modify an RBD. Selection **G** is used to graphically display the RBD. Selection **X** will return the user to the DATA INPUT Menu (3.2.1).

3.2.1.2.1 Enter Reliability Block Diagram

Keystrokes: (S) (E) (R) (E)

			M of N Data	
Sub #	Type	Elements	Min #	Capacity
1	p	b 1 2		

After selecting **E** from the previous menu, ETARA displays the above illustrated table with full screen editing capability. The entries shown above under the "Sub #", "Type", and "Elements" headings are the default assumptions. When entering data into this table, it is highly recommended that the user have on hand the annotated RBD as described in section 2.0 Preparing the Input.

The full screen editor has a vertical black column under each heading surrounded by a border. The data for each subsystem is defined horizontally, with the black spaces being the "window" for the alphanumeric input. For example, the black window for the subsystem number column is 4 spaces wide, allowing for a subsystem number 4 digits long.

To move from one window to the next, use the [Tab] key to move right and the [Shift] [Tab] keys to move left. The right and left arrow keys can also be used. The up and down arrow keys are used to move in those respective directions. If the block data input fills the screen, the [Pg Dn] key is used to page down the screen to obtain more space. The [Pg Up] key will page up the screen. The [Enter] key will terminate the full screen editor and return to the RELIABILITY BLOCK DIAGRAM Menu (3.2.1.2).

The RBD table editor can be used to edit existing data as well as define new data. The user can simply type over the default data or "mark" any existing data and delete it. The editor has on-line help screens which can be accessed by pressing the [F1] key. Complete instructions for using the full screen editor appear in Appendix B.

The appropriate procedure for completing the Reliability Block Data table is to begin in the upper left with a subsystem number. The user can then proceed horizontally with the subsystem type and other data or proceed vertically with the next subsystem number. Under the "Sub #" column heading, the user enters the integer corresponding to the subsystem number in the RBD. Under the "Type" column heading, the user enters the first letter of the type of subsystem; series, parallel, and M–of–N parallel, either variable or binary. If a parallel subsystem is an M–of–N Parallel arrangement, the "Min #" and "Capacity" columns under the "M of N Data" heading must be filled out as described below. As first described in section 2.0, when two blocks A and B are in series, it is equivalent to saying that block A **and** block B must be available for the subsystem to be available. When two blocks are in parallel, block A **or** block B must be available for the subsystem to be available. The situation where two blocks out of three blocks in parallel are needed for the subsystem to be available is termed "M–of–N parallel", in this case M=2 and N=3. M–of–N subsystems can comprise only **blocks; no subsystems can be in an m–of–n parallel arrangement.** However, there is no limit on the number of blocks in any type of subsystem, or the number of subsystems contained in any of the possible subsystem types, except M–of–N as just mentioned.

After the subsystem type selection is made (series, parallel, or M–of–N), the actual blocks and/or subsystems contained in that subsystem must be entered in the column labeled "Elements". The appropriate format for the response is to precede the block numbers in the subsystem with the letter "b" and precede the subsystem numbers contained in this particular subsystem with an "s". A space is not required between the "b" or "s" and the block or subsystem numbers. Numbers in a sequence such as [b 5 6 7 8] can be input with the beginning number, a "dash" [–], and the ending number [b 5–8]. Any combination of the above is allowed. Examples of allowed format for a subsystem are,

1) b 1 2 5–8 10 12–25 s 1 2 3–5

2) b2 s3 4

3) s 1 b 1

4) b3 4 5

It is important to remember that in subsystems which contain both blocks and other subsystems to delineate the blocks by a "b" followed by the block numbers and delineate subsystems with an "s" followed by the subsystem numbers.

When a subsystem type is a binary or variable M–of–N parallel, the last two columns of the editor under the "M of N Data" heading must be used to define the required further information. The column labeled "Min #" is the "M" in the M–of–N statement. That is, the number of blocks that need to be available so that the entire parallel arrangement of N blocks can be considered available. The distinction between binary and variable M–of–N subsystems is important in determining the capacity of the M–of–N subsystem. When binary M–of–N is desired, a **b** is entered in the "Type" column and a single capacity must be entered under the "Capacity" column heading. A binary M–of–N subsystem is available at this user–defined capacity when **M or more** blocks are available. When less than M blocks are available, the binary M–of–N subsystem is considered unavailable (zero output capacity).

When a variable M–of N is desired, a **v** is entered in the "Type" column and a set of capacities must be entered under the "Capacity" column heading. A variable M–of–N subsystem is available at the first user–defined capacity in this set when **M or more** blocks are available. The subsystem is available at the second user–defined capacity when exactly (M–1) blocks are available, and so on down to the last capacity in the set which occurs when exactly 1 block is available. When none of the blocks are available, the variable M–of–N subsystem is considered unavailable (zero output capacity). The set should contain **exactly M** number of capacities. The variable M–of–N subsystem allows greater flexibility in how an M–of–N parallel arrangement of blocks may degrade in terms of output capacity. The capacity defined here for an M–of–N subsystem will override the capacities of the individual blocks contained in this type of subsystem (see 3.2.1.1.1).

Pressing [Enter] will complete the RBD definition, save the data and return the user to the RELIABILITY BLOCK DIAGRAM menu (3.2.1.2). Pressing [Esc] will allow the user to leave the editor without saving changes.

3.2.1.2.2 Viewing the RBD

Keystrokes: (S) (E) (R) (G)

This selection is used to graphically display an RBD which has just been defined after working through the RBD table editor (3.2.1.2.1) or which has been reloaded from a saved system configuration file. The block number, type name, and installation time are displayed within each block of the RBD. The cursor keys, and the [Pg Dn], [Pg Up], [Home], and [End] keys may be used to move around the display. The viewing location in the diagram is displayed at the bottom of the screen.

Pressing [Enter] will return the user to the RELIABILITY BLOCK DIAGRAM Menu (3.2.1.2).

3.2.1.3 The SIMULATION PARAMETERS Menu

Keystrokes: (S) (E) (P)

SIMULATION PARAMETERS

Duration, number of runs, spares resupply

Minimum capacity for reliability

Probability of exceedence

eXit

This menu is used to define the data necessary to perform a simulation. Selection **D** allows the user to define the "duration", or length of time over which a system's behavior will be simulated, the "number of runs" or number of times that the duration will be repeated to build meaningful statistics, and the local and depot spares replenishment intervals. The **M** and **P** selections allow the user to define criterion for reliability analyses.

3.2.1.3.1 Duration, Number of Runs, & Spare Resupply Intervals

Keystrokes: (S) (E) (P) (D)

Duration	30	(Years)
Number of Runs	1	
Local Spares Replenishment Interval	90	(Days)
Resupply Cutoff	60	(Days)
Depot Spares Replenishment Interval	365	(Days)

This is a field editor that allows the user to enter five parameters governing a simulation.

In the first field, the user enters the duration – the number of years of system operation which will be simulated. ETARA assumes the system begins the simulation operating at 100% output capability with no failed blocks.

The next field deals with the number of simulations, or "runs" of the system over the given duration. There is no limit on the number of runs, except for the user's patience in waiting for the output. Longer run times will result as more events occur for a simulation, caused by many blocks and/or many failures and repairs, and the number of simulation runs performed. As one indication of the time involved in completing a series of simulation runs, the 10 availability simulation runs of a 30 year duration for the 10 block system illustrated in appendix X took 2 minutes and 23 seconds on a Dell 386 PC at 20 Mhz with a math co–processor (see 3.3 and Appendix X).

The final three fields deal with spares resupply. As mentioned in 2.0 and 3.2.1.1.1, ETARA determines block down times based on the availability of local and depot spares, the MTTR, and the local and depot spares resupply interval (see 3.2.1.3.1). Local spares refers to the number of initial spares of that particular block type at the system location available for immediate replacement. Depot spares are remotely located from the system and are delivered to the system only during the local spare resupply intervals. The initial quantity of depot spares are replenished according to the depot spares replenishment interval. If a local spare is available when a block fails, ETARA use only the block's MTTR to determine when the block will next become available. If there are no local spares but there are depot spares of the failed block's type, ETARA determines the down time to be the time remaining until the next local resupply action, plus the MTTR. If there is neither local nor depot spares of the failed block's type, ETARA determines the down time to be the time to the earliest resupply interval **after** the depot spares stock has been replenished, plus the MTTR.

Given the above discussion, it is seen that after the supply of local spares of a given block type runs out and depot spares are still available, the system would then receive spares from the depot according to the "Local Spares Replenishment Interval", subject to the "cutoff" condition described below. Note that the local spares quantities are NOT restocked. The local spares replenishment interval dictates when spare blocks are shipped from the depot to replace a failed block. The local spares replenishment interval is entered in the third field of this editor and must be an integer or real number ≥ 0.

A condition on the local spares replenishment interval, indicated by the fourth field in this editor, is the "Resupply Cutoff". The "cutoff" time (in days) is used to represent the finite time before a scheduled resupply action necessary to manifest and load spares on the resupply vehicle. For example, suppose the system under consideration is a space station in low earth orbit and the resupply vehicle is a space shuttle. Assume further that the shuttle visits the space station every 90 days to replenish the station's supplies and bring spare parts. Finally, assume that if a failure occurs on the space station, a spare part can be ordered from the earth and brought to the station with the next shuttle resupply visit. However, if a space station part fails 30 days or less from the next scheduled resupply visit, there will not be enough time to manifest and load a spare part on the shuttle. This scenario can be modeled in ETARA by assigning the "spares replenishment interval" a value of 90 days with a "cutoff time" of 30 days. This means that depending on when a part fails, a spare can be brought up to the station in as little as 30 days (failure occurred just before the cutoff time) or as late as 120 days (failure occurred just after the cutoff time so spare delivery had to wait until the following resupply visit). Allowable values for the cutoff time are ($0 \leq$ cutoff time $\leq$ replenishment interval).

The final field in this table is the "Depot Spares Replenishment Interval". The depot spares replenishment interval refers to the number of days between the restocking of original number of depot spares. If a system requires depot spares, ETARA executes as explained above and decrements the number of depot spares for the failed block type. The depot spare replenishment interval must be an integer or real number ≥ 0.

Each of these prompts have default responses as shown above which the user can type over.

3.2.1.3.2 Minimum Capacity for Reliability

Keystrokes: (S) (E) (P) (M)

Year	Minimum Capacity
0	100
1	50

This selection is a full screen editor which allows the user to define a "minimum capacity" of the output of a system which is only used by ETARA as a success criterion when performing reliability simulations. In ETARA, the reliability (with or without repair) of a system to operate **at or above** this user–defined minimum capacity is calculated (see 3.3).

In this editor, the user defines the points in time under the "Year" column heading to which a"minimum capacity" threshold will be assigned as the system's success criterion for a reliability simulation. The points in time, given in years, signify the point during a system's simulation at which the corresponding minimum capacity threshold, in percent of the total system capacity, takes effect. In the example illustrated above, ETARA will assign success criterion from the beginning of the simulation (year 0) to year 1 of a minimum of 100% system capacity followed by a minimum of 50% system capacity from year 1 to the remainder of the duration. In a individual run during a reliability simulation, if failures within a system results in a system capacity below the minimum capacity at any time, even if only briefly, the particular simulation run is stopped, the violation of the success criterion noted, and a new simulation is begun. See 3.4.2 for explanation of the reliability results for this particular option.

If no information is entered by the user, ETARA will default the minimum capacity requirement to zero for the entire duration of a system.The full screen editor for this section is identical to the editors previously described. See appendix B for more complete instructions.

3.2.1.3.3 Probability of Exceedence

Keystrokes: (S) (E) (P) (P)

PROBABILITY OF EXCEEDENCE
Profile capacity data
Multiple capacity level data
eXit

This selection is a full screen editor which allows the user to define probability of exceedence parameters. As the phrase implies, probability of exceedence refers to the probability that, at user–specified points in time, a system's capacity will exceed user–specified output capacity thresholds. The user is given the choice of two types of probability of exceedence setups.

The first option, selection **P**, allows the user to define a capacity profile as a function of time. This is equivalent to a load profile or power demand curve in electrical power system analyses. Data is entered as points–in–time (yrs)/capacity level (%) pairs representing points along a capacity profile. It is important that capacity profile data be entered in pairs, with a capacity level corresponding to each point–in–time, in years, so **the number of periods and capacity levels should be equal.** In the example illustrated below, the user has specified a 75% capacity level from year 0 to year 1, followed by a 50% capacity level from year 1 to year 2, followed by an increase back to 75% at year 2. Through a number of simulation runs, ETARA will evaluate the probability that the user–defined capacity profile will be met or exceeded. See 3.4.1.4 for discussion of the results.

Keystrokes: (S) (E) (P) (P)(P)

Probability of Exceedence Data

Time, yrs	Capacity levels
0	75
1	50
2	75

The other option available to the user, through selection **M** from the "Probability of Exceedence" menu, is to enter a set of points–in–time and a set of capacity levels independent of one another. During a simulation, ETARA will take a "snap shot" of the capacity of the system at each user–specified point–in–time to see if it meets or exceeds the set of user–specified capacities. This data is used to generate a type of "instantaneous availability" matrix which gives the probability that the system operated at or above the user-specified capacity levels at the user-specified points-in-time. See 3.4.1.4 for further discussion of the results.

If the user wishes to enter the points-in-time or capacity levels as a sequence with regular intervals, the set can be input with the beginning number, a "dash" [–], the ending number, a "comma" [,], and the interval.

For example:

Keystrokes: (S) (E) (P) (P)(M)

Probability of Exceedence Data

Time, yrs	Capacity levels
0	**0–50, 10**
1–2,.25	
3	

is equivalent to:

Probability of Exceedence Data

Time, yrs.	Capacity levels
0	**0**
1	**10**
1.25	**20**
1.50	**30**
1.75	**40**
2	**50**
3	

In the example illustrated above, at **each point–in–time** given in the left column, ETARA will evaluate the probability of exceeding **each of the capacity levels** in the right column.

The full screen editor for this section is identical to the editors described previously. See appendix B for more complete instructions.

3.2.2 The SYSTEM FILE MANAGEMENT Menu

Keystrokes: (S) (F)

SYSTEM FILE MANAGEMENT

Load a previously saved system

Save the present system

Delete a system

Rename a system

eXit

The SYSTEM FILE MANAGEMENT menu is used to Load, Save, Rename and Delete system configuration files. The system configuration files contain all the information from the DATA INPUT Menu (3.2.1); the system's RBD, block data, numbers, and initial ages, installation times, parameters of the simulation and the spare resupply interval data. This information is all that is necessary to perform RAM simulations.

On selection of choices **L** and **D**, ETARA will respond by listing the extended filenames of previously stored systems in reverse chronological order according to the times they were saved. The size, date ,and time saved are displayed along with the names. For those files that have not been assigned extended names, the DOS file names will be displayed. The user selects a file with the up and down cursor keys, and presses **[Enter]** when the desired file is highlighted. For options **L** and **D**, the file will be loaded or deleted, respectively.

On selection of choice **R**, ETARA will display the list of filenames from which the user can choose as described above. The user is then prompted for a new extended file name. The name can be made up of any alphanumeric characters, however, the **first character must be a letter**. In the case of files that do not have extended names, this rename procedure will create one for them.

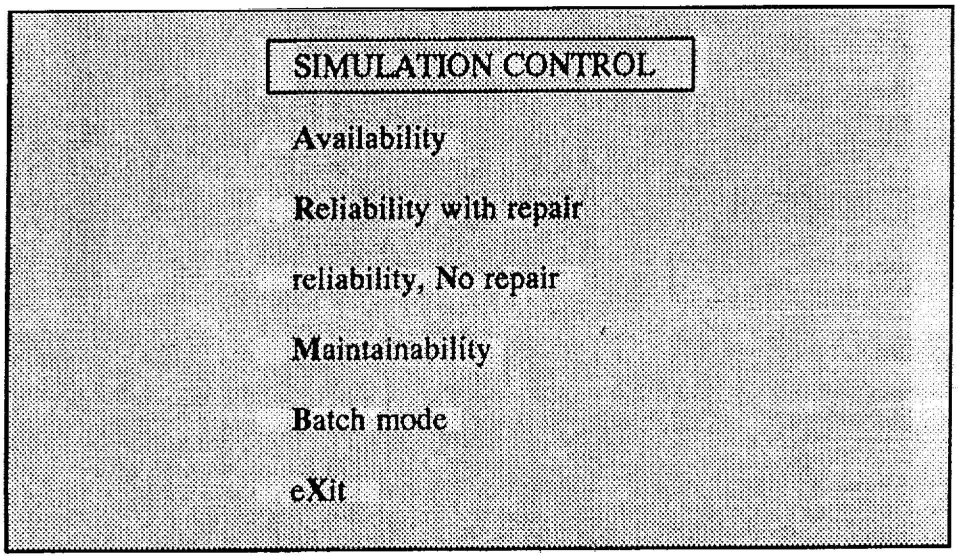
Similarly, selection of **S** will display the filename list and immediately prompt the user for an extended name for the system to be saved. The displayed filename list should enable the user to create a name for the new file to sufficiently describe it and differentiate it from the others. As stated above, the name can be made up of any alphanumeric characters, with the exception that the first character must be a letter.

Upon completion of any of these selections, ETARA returns to the SYSTEM DEFINITION Menu (3.2).

If the user chooses NOT to load, save, rename, or delete a system from the stored systems list, the **[Escape]** key can be pressed. ETARA will then sound a "beep", flash a message and return the user to the SYSTEM DEFINITION Menu (3.2).

3.3 The SIMULATION CONTROL Menu

Keystroke: (R)



Selecting the "**R**un simulation" option from the ETARA MAIN MENU brings up the "SIMULATION CONTROL" menu. This menu allows the user to choose from **A**vailability, **R**eliability with repair, reliability with **N**o repair, and **M**aintainability simulations, as well as a multiple run **B**atch mode. ETARA immediately begins the simulation when a key is pressed, given that the user has reloaded a saved system configuration file or has just finished defining a new system. e**X**it will return the user to the ETARA MAIN MENU (3.1).

The Availability simulation is carried out assuming that the system is operating at 100% output capability with no failed blocks at the beginning of the simulation. The system's block failures and repairs constitutes the events during a simulation. Block time–to–failure and time–to–repair are determined via Monte–Carlo methods using the user–defined reliability (exponential MTBF and/or the Weibull shape and scale factors – see 3.2.1.1.1) and maintainability (MTTR, spares replenishment interval and cutoff time – see both 3.2.1.1.1 and 3.2.1.3.1) data, respectively. At each event, ETARA solves the the reliability block diagram to determine the output capacity of the system, i.e., its capacity state. The simulation is performed for the specified system lifetime or duration (see 3.2.1.3.1). ETARA has completed a single simulation "run" when the end of one duration is reached. ETARA then resets the system to its initial state and repeats the simulation for another duration. This process is repeated until the user–specified number of runs is reached. The probability of exceedence statistics are also accrued during an Availability simulation.

The same basic process described above is used when performing the Reliability simulations. The difference is that when a block failure causes the system's output to fall below a user–specified minimum output capacity (see 3.2.1.3.2), the current simulation run is terminated and a new run is initiated. A run is successful if it reaches the duration of the simulation without falling below the minimum capacity. The system's reliability at or above the specified minimum capacity over the given time period (duration) is calculated as the ratio of the number of successful runs to the total number of runs (maximum runs) attempted. The "Reliability with repair" option proceeds in the manner of the Availability simulation with the additional conditions just described. For the "reliability, No repair" option, all block MTTRs are set to a very large number to ensure that no failed block returns to service.

During a Maintainability simulation, only failures and repairs of the system's blocks are simulated and stored. ETARA does not determine the system capacity states (and state availabilities). This selection is intended for use in illustrating a system's demand for maintenance on a yearly basis. The same information can be obtained in a longer–running availability simulation. However, the maintainability simulation will run faster since it does not take time to calculate the system capacity states.

While performing a simulation, ETARA displays information describing the filename of the system being used, the type of simulation being performed, the number of runs completed out of the total number of runs, and the estimated time remaining to complete the total number of runs. An example for an Availability simulation is given on the following page. The estimated time remaining is read from left–to–right in hours:minutes:seconds. In the example, there is an estimated 10 minutes and 19 seconds remaining for completion of the 1,000 runs.

ETARA Simulation in Progress

filename

Availability

Run 42 out of 1000 completed

Estimated time remaining: :10:19

(X) to exit early

If the user presses **X** during a simulation, ETARA will internally assign the maximum number of runs parameter to the next run number, thereby ending the simulation at the completion of the current run. Analytical results up to this run number can still be obtained from the SIMULATION RESULTS ANALYSIS Menu (3.4).

ETARA will briefly display the "ETARA Simulation Complete" message on the screen when the maximum number of runs have been reached or the user exits early, then return to the ETARA MAIN MENU.

The **Batch** Mode selection from the "Simulation Control" menu allows the user to choose a number of system files and assign a type of simulation to each file. ETARA will then successively execute each simulation, saving the results as it goes. After **B** is selected, ETARA displays a list of stored system files below a list of the types of simulations,

```
a: Availability
r: Reliability with repair
n: reliability, No repair
m: Maintainability
________________________________

r     || filename 1
a     || filename 2
```

The user can choose to run a type of simulation on any system file by entering the appropriate letter in the column to the left of the filename. In the example, a Reliability with repair simulation was chosen for system filename 1 while an Availability simulation was chosen for system filename 2.

To start the batch run, the user presses **[Enter]**. ETARA will load the first stored system in the queue and perform the corresponding simulation on it. After the simulation ETARA will store the result data in a result file with the same name as the system file. ETARA will continue to do this until it reaches the end of the system file queue.

3.4 The SIMULATION RESULTS ANALYSIS Menu

Keystroke: (A)

```
SIMULATION RESULTS ANALYSIS

Availability results

Reliability results

Maintainability results

Time check

File management

eXit to main menu
```

The SIMULATION RESULTS ANALYSIS Menu allows the user to view Availability, Reliability and Maintainability analytical results from previously completed simulations. The

File management selection allows the user to save, re–load, rename and delete results files as well as obtain hard copies of the results. The Time check selection displays clock time used to complete the simulation. eXit will return the user to the ETARA MAIN MENU (3.1).

3.4.1 The AVAILABILITY RESULTS ANALYSIS Menu

keystrokes: (A) (A)

AVAILABILITY RESULTS ANALYSIS

System availability

Block availability

Continuous state behavior

Probability of exceedence

eXit

The AVAILABILITY RESULTS ANALYSIS menu presents the user a number of choices of analytical results displays obtained from an availability simulation. Selection **S** allows access to system–level availability results displays while selection **B** displays results for each block or block type in the RBD. Selection **C** will display statistics regarding the system capacity states which occurred during the simulation. eXit will return the user to the SIMULATION RESULTS ANALYSIS Menu (3.4).

The System availability and Continuous state behavior displays combine to give a comprehensive description of a system's behavior in terms of availability. Information from these two displays include the number and capacity of whatever system operating states actually occurred, from 100% down to 0%, the availability of each capacity state, the average continuous time that a system operated at a given capacity state, the average number of occurrences of a capacity state, the availability of a capacity state or greater, and the total system's equivalent availability. Also, histograms of the 100% and 0% capacity state durations are available in selection **C**.

The Probability of exceedence selection presents the results of the statistical sampling performed on the system for either the cumulative or discrete probability of exceedence options.

3.4.1.1 System Availability Results

Keystrokes: (A) (A) (S)

SYSTEM AVAILABILITY RESULTS

Tabular results

Graphics display

eXit

System availability results can be displayed either in **T**abular or **G**raphic format. The tabular selection is illustrated below.

Keystrokes: (A) (A) (S) (T)

SYSTEM CAPACITIES AND AVAILABILITIES

System Capacity States	Time at Each Cap. State, Yrs	Availability of Each Capacity St.	Availability of Capacity St. or Greater	Equivalent Availability
1 100.0	7.2	.72	0.72	.720
2 75.0	1.0	.10	0.82	.075
3 50.0	1.4	.14	0.96	.070
4 25.0	0.3	.03	0.99	.008
5 0.0	0.1	.01	1.00	.000
Summation	10.000	1.0000		.873

In this example, during 10 years of operation, the first column in the display shows that the system functioned at five **system capacity states**: 100%, 75%, 50%, 25%, and 0%. The next two columns to the right show the time in years and the percentage of the total time that the system functioned at each state, respectively. The percentage of time at a particular state is also known as **state availability**. Alternatively, this implies that at any given time in the system's operation over the ten years, there is a 72% chance of finding it operating at 100% capacity. The fourth column, "Availability of Capacity State or Greater", is a cumulative sum of state availabilities beginning with the 100% state availability and ending with a 1.0 for the last state listed. The third entry down the column shows that the system will operate at the 50% level **or greater** 96% of the time. Alternatively in this case, at any given time in the system's operation over the ten years, there is a 96% chance of finding it operating at 50% or greater capacity. The final column shows the **equivalent availability** calculation. The system's equivalent availability is shown at the bottom of the column under the horizontal line, 87.3% in this case. The entry for individual capacity states is an intermediate result obtained by multiplying the capacity state (%) by its state availability (%) and dividing by 100. The intermediate results for each state are then summed to determine the total system's equivalent availability.

Equivalent availability is a single measure of the overall "goodness" of a system. It is the ratio of the total actual system production over a time period (considering degraded output states due to failures) to the total ideal production (i.e. 100% output 100% of the time). Based on the previous paragraph, the area under the graph of state availabilities versus the system capacity states is equal to the system's equivalent availability. It can be viewed as a type of weighted average system capacity. There are many alternative ways of expressing equivalent availability. For example, suppose the system is a power station which can produce 100 MW at its 100% state. A system equivalent availability of 87.3% can be obtained either by the power station operating as indicated in the earlier illustrated table, or by operating at 87.3% output capacity for 100% of the time, or by operating at 100% output capacity for 87.3% of the time and at 0% for 12.7% of the time. The same energy is produced over the same time period for each of these cases.

An important point first mentioned in 3.2.1.1.4 Block Installation Times is repeated here. Before all blocks are installed, the system's maximum capacity will usually be less than 100%. In ETARA, availability results are normalized to the maximum possible output capacity during a given time period. This means that during the period when blocks are being installed, occurrence of the maximum capacity state possible, even though it could be less than the 100% ultimately possible, will be bookept under the 100% capacity state. In the results, the 100% capacity state availability includes occurrences of any state which was the maximum possible state during a given time period.

The system availability Graphics display is illustrated in figure 2. This display is a graph of system Capacity (y–axis) versus Availability (x–axis). The axis have been normalized with 1.0 corresponding to 100%. This is an "exceedence plot" in that for a given availability, the plot shows the capacity that the system operated **at, or above**. In the figure, for about 90% of the time the system will operate at or above 75% capacity. A given state availability can also be determined from the plot by looking at the horizontal length of the power capability plateaus. Figure 2 shows the 100% capacity state is available about 85% of the time. As described earlier, the system equivalent availability, which is about 93% in this case, can be obtained from the area under this curve.

Keystrokes: (A) (A) (S)(G)

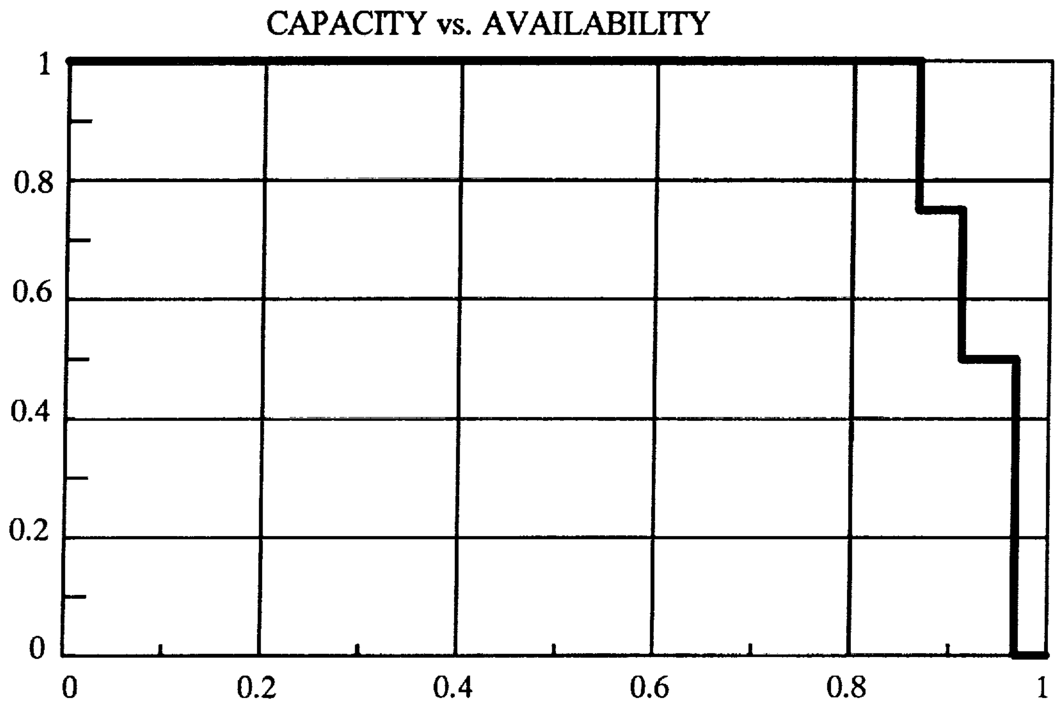


Figure 2 – Graph of System Capacity (y–axis) vs. Availability (x–axis)

3.4.1.2 Block Availability

Keystrokes: (A) (A) (B)

BLOCK AVAILABILITY RESULTS

Individual

by Type

eXit

At this point, the user can choose between block failure and repair results displayed either by Individual blocks or by block Types. The individual block selection displays data for every block which appears in the RBD. The information is displayed in tabular form under the header illustrated below beginning with block number one and continuing through the largest block number.

Keystrokes: (A) (A) (B) (I)

INDIVIDUAL BLOCK FAILURE AND REPAIR RESULTS

Block		# of Failures		Downtime, Yrs.			Delay Time	
				Raw	Per Dura	% Dura	Raw	Per Dura
Name	No.	Raw	Per Dura	(Years)	(Days)		(Years)	(Days)

After the block name and number are displayed, the total number of failures that the block experienced throughout the duration of every run is listed under the "Raw" heading. The number of raw failures divided by the number of simulation runs gives the average number of failures per duration, listed under the "Per Dura" column. The "Downtime" column gives the total time that the block was unavailable either while being repaired or waiting for a spare. The Raw column lists the total down time, in years, for all simulation runs, while the Per Dura column lists the average time down per duration, in days. Also, the average percent of the duration that the block was unavailable is listed under the "% Dura" heading. The subheadings under the "Delay Time" heading list the total time for all simulations, Raw in years, and average time per duration, Per Dura in days, that a block was unavailable and waiting for a spare to be supplied at the next spares replenishment action. The active repair time can be obtained by subtracting the Delay Time from the Down Time.

The results by block type are displayed under the following heading,

Keystrokes: (A) (A) (B) (T)

BLOCK TYPE FAILURE AND REPAIR RESULTS

Block Type		# of Failures Per		Repair Time Per:		Percentage Of Total		
				Dura	Year	Repair	Down	Delay
Name	Quant	Dura	Year	(Days)	(Hours)	Time	Time	Time

In this display, results are listed by the different block **types**. This information is useful in determining the relative sensitivities of the different block types with respect to the number of failures and repair, delay and total down times. The block type list is ordered from top to bottom by decreasing downtime (i.e. the block type at the top of the list spent the most time down compared to other block types). The total quantity of blocks of each type are given along with the type name. The total number of failures are given per duration (number of total failures divided by number of simulation runs) and per year (failures per duration divided by number of years in a duration). Next, the active repair time for each block type per duration (in days) and per year (in hours) is given. The total repair time per year for all block types should be the same number as reported for the total yearly maintenance man–hour average in the MAINTAINABILITY RESULTS display (see 3.4.3). Finally, each block type's percent contribution to the total repair, down, and delay times are displayed. These three columns should each sum to 100%.

3.4.1.3 Continuous State Behavior

Keystrokes: (A) (A) (C)

CONTINUOUS STATE BEHAVIOR

Tabular results

Histograms

eXit

Selection **T** will bring up a tabular display of every system capacity state which occurred in the simulation along with the availabilities of each state, the average continuous time that the system occupied that state, and the average number of occurrences of the state. Selection **H** will bring up another menu which allows the user to choose between histogram displays of the 100% or 0% capacity continuous state times.

The following is an illustration of the tabular results display corresponding to the results first given in 3.4.1.1 System Availability Results,

Keystrokes: (A) (A) (C) (T)

AVERAGE CONTINUOUS STATE TIME FOR EACH CAPACITY

System Capacity States	Time at Each Cap. State, Yrs	Availability of Each Capacity State	Average Continuous State Time	Average Num. of Occurrences Per Duration
1 100.0	7.2	.72	186.56	14.087
2 75.0	1.0	.10	47.79	7.638
3 50.0	1.4	.14	45.91	11.131
4 25.0	0.3	.03	17.26	6.344
5 0.0	0.1	.01	6.98	5.228
Summation	10.000	1.00		

On comparing the two displays, it is seen that the first three columns list the same information: System Capacity States, Time at Each Capacity State,Yrs, and Availability of Each Capacity State. The additional information presented in this display is the Average Continuous State Time (in Days) and the Average Number of Occurrences Per Duration in the two columns on the right.

For every simulation run throughout a system's duration, ETARA keeps a running total of the number of occurrences of a particular state. The total number of occurrences divided by the number of runs gives the average number of occurrences of the state per duration (rightmost column). Dividing the Time at Each Capacity State by the Average Number of Occurrences Per Duration results in the arithmetic Average Continuous State Time, given in Days, listed the second column from the right.

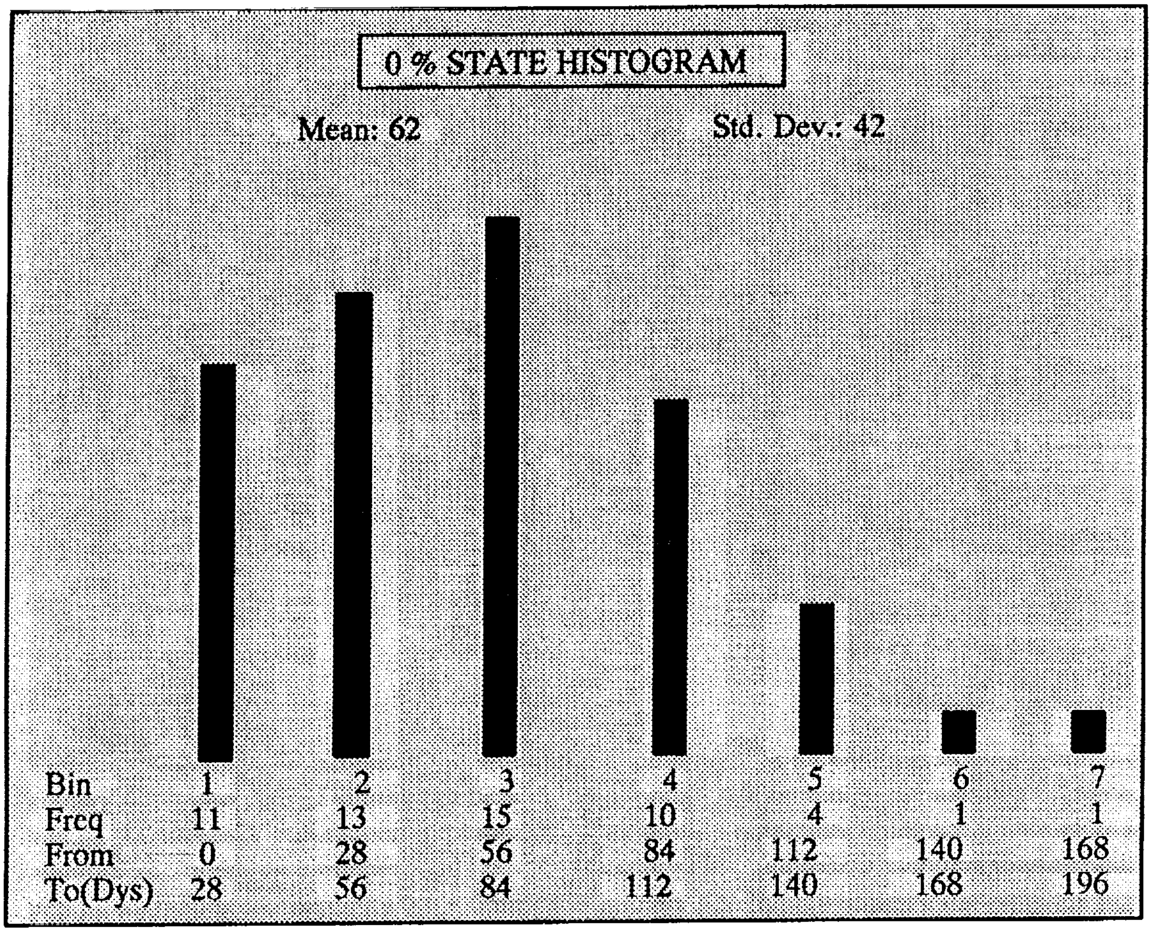
The user is presented with the histogram menu on selecting **H** from the CONTINUOUS STATE BEHAVIOR menu, illustrated as follows,

Keystrokes: (A) (A) (C) (H)

```
100 % AND 0 % STATE HISTOGRAMS

    Full (100 %) capacity

    Zero capacity

    eXit
```

On selection of either **F** or **Z**, a frequency distribution histogram of the number of occurrences of the capacity state which lasted for a particular range of time is displayed along with the calculated mean and standard deviation.

Keystrokes: (A) (A) (C)(H)(Z)



During the simulation, ETARA stores the length of time the system spent in every occurrence of the 100% and 0% capacity states. The bins are equal intervals of time (days), the number of which is internally calculated by ETARA from the Sturgess rule equation,

$$\text{Number of bins} = 1 + 3.3 \log n$$

where n is the total number of occurrences of the capacity state. The total number of bins and the maximum continuous time spent in the capacity state are used to calculate the bin interval. The bin interval is indicated on the display by the From and To (Dys) headings. In the example above, bin 1 has an interval from 0 to 28 days. The number of occurrences of the 0% state which lasted from 0 to 28 days is indicated by the Freq (Frequency), indicated as 11 above. The height of the bars are drawn accurate relative to one another, but are not to any actual scale. The mean and standard deviation of the 0% state occurrences are also given; the mean being 62 days with a standard deviation of 42 days in the example.

The standard deviation results are given as a means of indicating the variation in the mean values. However, the user should use caution in interpreting this information. Before a system simulation is performed, there is usually no prior knowledge of the statistical frequency distribution of the 100% and 0% continuous state time intervals. The calculation of the standard deviation for these states does not mean that the continuous state time intervals form a normal frequency distribution.

3.4.1.4 Probability of Exceedence

ETARA automatically selects the type of probability of exceedence display depending on the option selected by the user before running the simulation (see 3.2.1.3.3). If the user selected the probability of exceeding a capacity profile, then the probability that the system will meet or exceed this capacity profile based on the number of simulation runs performed will be displayed, in percent.

Keystrokes: (A) (A) (P)

PROBABILITY OF EXCEEDING CAPACITY PROFILE
82.6

This probability is calculated by the equation:

$$\text{PROBABILITY} = \frac{\sum_{i=1}^{N} p_i \bullet t_i}{\sum_{i=1}^{N} t_i}$$

where p is the individual probability, based on a number of simulation runs, that the system's output capacity will be equal to or greater than a specific capacity level over an interval of time, t. N is the number of capacity levels (over corresponding time intervals) within the profile defined by the user.

The alternative probability of exceedence display is used if the user had selected the multiple capacity level criterion. ETARA calculates a probability of exceeding each capacity level at every point-in-time specified by the user based on the system behavior over a number of simulation runs. The results are displayed in a table.

PROBABILITY OF EXCEEDENCE

Capacity		Time, yrs .0	.5	1.0	1.5
1	0.0	1.0	1.0	1.0	1.0
2	25.0	1.0	1.0	1.0	1.0
3	50.0	1.0	.98	.95	.91
4	75.0	1.0	.96	.93	.89
5	100.0	1.0	.94	.90	.87

The system capacity levels specified by the user are listed vertically along the left side while the user–specified time periods are given horizontally in the first row across the top. The probability that the system's capacity will be equal to or greater than a given capacity at a point in time is found at the intersection of a given point in time and capacity. In the example, at year 1.0, there is a 93% probability that the system's capacity will be equal to or greater than 75%. If the table contains more data than can be displayed on one screen, the user can use the left and right arrow keys and the [Pg Up] and [Pg Dn] keys to move around the display.

Press the **[Enter]** key to exit from either of these displays.

3.4.2 RELIABILITY RESULTS

Keystrokes: (A) (R)

SYSTEM RELIABILITY

Number Of Successes	Simulated Reliability
465	.93

The Reliability Results selection displays the numerical results from a reliability simulation (see 3.3). The simple format is illustrated above. The number of successful simulation runs and the simulated reliability, calculated by dividing the number of successful runs (465) by the total number of runs attempted (500, not shown), are displayed. As described in section 3.3, ETARA calculates the reliability of a system to operate **at or above** a user–specified minimum capacity as a function of time. A successful run occurs if the system's capacity remains greater than or equal to the user–defined capacity threshold **throughout the duration**, or life of the system simulation.

3.4.3 MAINTAINABILITY RESULTS

Keystrokes: (A) (M)

MAINTENANCE MAN-HOURS PER YEAR

Year	Mean, Hours	Std. Dev., Hours
1	33.08	24.79
2	47.73	29.00
3	44.35	23.82
3 Year Ave. =	41.72	7.67

The Maintainability Results selection displays maintenance man–hour results and statistics obtained from a maintainability or availability simulation (see 3.3). The display format is a vertical listing of the year, from year 1 through the last year of the duration, with the corresponding mean maintenance man–hours for that year along with the standard deviation, also in hours, from the mean. These statistics are determined from data stored for all simulation runs for a particular case. At the bottom of the display, the average maintenance man–hours over all years of the duration is given along with the corresponding standard deviation (hours). Note that the standard deviation reported at the bottom is **not** the average of the standard deviations reported for the individual years.

In the example above, the mean maintenance man–hours for year 1 for the number of simulations performed is 33.08 hours with a corresponding standard deviation of 24.79 hours. The average maintenance man–hours over the three years of the duration is 41.72 hours with a corresponding standard deviation of 7.67 hours.

3.4.4 TIME CHECK

Keystrokes: (A) (T)

TIME CHECK

Computation clock time = :7:13

This selection displays the clock time used to perform the simulations. The simulation depicted in the above example took 7 minutes and 13 seconds to complete.

3.4.5 The RESULT FILE MANAGEMENT Menu

Keystrokes: (A) (F)

RESULT FILE MANAGEMENT

Load previously saved result file

Save the present results

Delete a result file

Rename a result file

Print the present results

eXit

The RESULT FILE MANAGEMENT Menu is used to **L**oad, **S**ave, **R**ename and **D**elete "Result" files. The Result files contain all the information needed to display Availability (3.4.1), Reliability (3.4.2), or Maintainability (3.4.3) results. Since this menu uses the same procedures and format to load, save and delete files as described in 3.2.2, for the SYSTEM FILE MANAGEMENT Menu, the user is referred to that section for details.

Selection **P** will enable the user to get a hard copy of the present results, whether just obtained by a simulation or reloaded from a saved Result file. For both Availability and Reliability results, the hard copy contains information of the number of blocks in the RBD, the duration, number of runs, resupply interval, spares cutoff period and a tabular listing of block data: quantity, capacity, MTBF (random), mean life (wearout), MTTR, shape factor, initial ages, installation times and number of local and depot spares (see 3.2.1.2). For Availability simulations, the hard copy contains the System Availability (3.4.1.1), Continuous State Behavior tabular results (3.4.1.3) results, and the MAINTAINABILITY RESULTS (3.4.3). For Reliability simulations, the RELIABILITY RESULTS (3.4.2) information is printed.

eXit will return the user to the SIMULATION RESULTS ANALYSIS menu (3.4).

3.5 EXIT ETARA

After **X** is pressed to exit from ETARA, the following prompt will appear,

Has the system configuration been saved? Y/N

This prompt exists so that the user does not inadvertently leave ETARA without saving a newly defined system in a System Configuration file. On responding with an **N**, ETARA returns to the

Main Menu, at which the user should select **S** and **F** to arrive at the SYSTEM FILE MANAGEMENT menu (3.2.2), using selection **S** to save the system information.

If the user desires to leave ETARA without saving the system, or the system has already been saved, pressing **Y**at the prompt will terminate ETARA execution.

4.0 ETARA Algorithm Background

The intent of this section is to give more detailed descriptions of some of ETARA's features.

4.1 Event Simulation

ETARA is a "next event" driven simulation. The next event is either a block becoming available (up) or unavailable (down). A block is the lowest level of division in an RBD and may represent hardware, software, or anything else which has reliability and maintainability characteristics. Each time a block changes its status it could have an affect on the output capacity of the entire system. At every event, the new status of the block, the time that the block had existed in its previous state, the new system status, and the time the system had existed in its previous state are all recorded.

To illustrate the next event simulation, a simple block diagram will be analyzed over a small period of time. The RBD in Figure 1 will be used as the system. For ease of demonstration, each block will be assumed to have a capacity of 100%. This implies the system, as well as the blocks, will have a binary status, either 100% or 0%. At the beginning of the simulation, all of the blocks are assumed to be available and therefore the system is available at the 100% capacity state. As described in detail in the next section, the first time of failure for each block is computed via a random number generator and either, or both of the exponential or Weibull functions. The earliest failure, which is the minimum of all the first time to failures, is the first event of the simulation. From figure 3 (next page), block 4 can be seen to have the earliest failure at 0.8 years.

The system clock is then advanced to this event. The time to repair block 4 is computed, 0.7 years for this example. Since the clock is at 0.8 and the block will not be fixed until 0.7 years have transpired, the block will become available when the system clock reaches 1.5 years. Also, the new status of the system with block 4 down is found. In this case, the entire system went down when block 4 went down. Since the system was up from 0 to 0.8 years, the duration of 0.8 is recorded as the time the system was available at 100% capacity.

Looking at each block for the next event, it is seen that the earliest event is the failure of block 2 at 1.0 year. The system clock is advanced to 1.0 and the time to repair is computed. Let the time to repair be 0.2 years; this is added to 1.0 and defines the next event for block 2. The system was down from 0.8 to 1.0 years and is still down, its status is has not changed.

Block #:		1	2	3	4	5	6	7	8	9	10
Event	1	3.0	1.0	5.0	**0.8**	4.3	2.0	1.8	5.5	4.0	3.7
Timelines	2	3.0	**1.0**	5.0	1.5	4.3	2.0	1.8	5.5	4.0	3.7
	3	3.0	**1.2**	5.0	1.5	4.3	2.0	1.8	5.5	4.0	3.7
	4	3.0	2.7	5.0	**1.5**	4.3	2.0	1.8	5.5	4.0	3.7
	5	3.9	2.7	5.0	6.1	4.3	2.0	**1.8**	5.5	4.0	3.7

Events:	System Clock	System Capacity, %
0) New System	0.0	100
1) Block 4 failure	0.8	0
2) Block 2 failure	1.0	0
3) Block 2 repair	1.2	0
4) Block 4 repair	1.5	100

Figure 3 – Example of ETARA "Next Event" Determination

The next event occurs when block 2 is repaired; the system clock is advanced to 1.2 years. The next time to failure for block 2 is found to be 1.5 years and is added to 1.2. Block 2 was unavailable from 1.0 to 1.2 years, an elapsed time of 0.20 years; this is recorded as the time block 2 was down. Even though block 2 has been repaired, the system is still down. The next event is the repair of block 4 at year 1.5; the system clock is advanced to 1.5. The next time to failure for block 4 is computed as 4.6 years and is added to 1.5, giving the 6.1 entry under block 4. Just as with block 2, the time that it was down is recorded. With block 4 becoming available the system has again become available. The system originally became unavailable at 0.8 years and the system clock has advanced 0.7 years; this value is recorded as time the system was down.

The simulation continues to operate until the system clock reaches the duration as specified by the user. The program always looks for the next event, at which time a block is either failing or being repaired. At each event the following information is determined: the new status of the block, the time the block had existed in its old status, the new status of the system, and time the system had spent in its old status (if its status has changed). Additionally, a running total is kept on how many times each block fails and how many times the system has existed in a particular output state.

The number of runs that is specified by the user determines how many times the program performs the simulation for the system duration. In each run, ETARA proceeds through the event simulation as described. A run can be thought of as forming a time line with events marked all along it. Many time lines must be developed so that an accurate statistical average may be calculated and the expected operation of the system can be approximated. The more the simulation is run, the more statistically significant the results.

4.2 Event Time Generation

The events in an ETARA Monte–Carlo simulation are block failures and repairs. The phrase Monte–Carlo refers to the generation of random numbers which is accomplished in ETARA with a standard APL2 operator. The block time–to–failure and time–to–repair intervals are generated by inserting the random numbers into a statistical distribution function. The result is time intervals that are distributed according to a user–defined distribution function which approximates the failure and repair characteristics of the block.

ETARA uses the Weibull reliability distribution function to generate event times. The advantage of using the Weibull distribution function is that it can be used to approximate a wide variety of failure and repair distributions. In terms previously used in this manual, the equation for the Weibull reliability distribution function is

$$R = \exp\{-[(t+\text{location})/\text{scale}]^{\text{shape}}\},$$

where t is the time period, and shape, scale, and location denotes the three parameters of the Weibull function. The shape and scale factors can be adjusted to modify the form of the distribution. Note that when the shape factor is 1, the Weibull distribution reduces to the exponential function where the scale factor is equivalent to the MTBF. The location parameter is equivalent to the block initial age or failure free period as described in section 3.2.1.1.3. A positive value for this parameter will move the origin of the Weibull reliability curve to the left, modeling a block's initial age prior to the beginning of the simulation. A negative value will move the origin to the right, modeling an initial failure free period where a block can not fail with respect to the Weibull function (the block could fail via a random failure if a random MTBF is specified for use in conjunction with the Weibull parameters modeling wearout).

It should be pointed out that this definition of the Weibull function may differ slightly than what may be found in reliability textbooks. For example, a common definition is as follows;

$$R = \exp\{-(t-\text{location})^{\text{shape}}/\text{scale}\},$$

where,

$$\text{shape}_{\text{ETARA}} = \text{shape}$$

$$\text{scale}_{\text{ETARA}} = \text{scale}^{1/\text{shape}}$$

$$\text{location}_{\text{ETARA}} = -\ \text{location}$$

In ETARA, the scale factor is calculated internally from the mean life and shape factor. The reason for the sign change on the location parameter is to allow the user to enter positive numbers for blocks which have experienced initial aging prior to the beginning of the simulation.

The actual generation of event times in ETARA is described as follows. The Weibull reliability distribution function is rearranged to give the time period, t, as a function of reliability, R, and the shape, scale, and location factors,

$$t = (\text{scale} \times (-\ln(R))^{1/\text{shape}}) - \text{location}$$

Reliability, R, is expressed as a fraction between 0 and 1. Uniformly distributed random numbers are generated between 0 and 1 and substituted for R in the above equation. The shape, scale, and location factors are given by the user or calculated from user input. The result is time intervals, t, which fit the statistical distribution function defined by the Weibull shape and scale factors.

It is important to understand that in an ETARA simulation, the location factor is only used to modify the **time–to–first–failure** for those blocks which have initial ages or failure free periods. For each subsequent time–to–failure, the location parameter is set to zero. If a block's failure characteristics are being modeled by both an exponential as well as a Weibull distribution, a time–to–failure is generated for both distributions. ETARA takes the minimum of the two as the block's next time–to–failure.

4.3 Collapsing the RBD

ETARA operates on series/parallel system RBD configurations as explained in section 2.0. After each event occurs in a simulation, ETARA "collapses" the RBD composed of many blocks, to one block, which has a capacity that represents the state of the system. Generally, two simple rules are followed to accomplish this:

1) Add the capacities of parallel blocks and/or subsystems.

2) Take the minimum capacity of series blocks and/or subsystems.

M–of–N parallel subsystems have their own special rules which are described in detail in section 3.2.1.2.1.

This collapsing process is performed "from the inside out". That is, the capacity of the innermost subsystem is determined first from the general rules mentioned above. This effectively reduces the subsystem to a single "block" with a single output capacity. Subsequent subsystem capacities are calculated depending on the status of their constituent blocks and/or subsystems. Finally, the system RBD can be represented by one "block" operating at the resultant output capacity.

The process described above is repeated for each event, whether it is a block failure or repair, to determine the system's output capability after each event. This process accounts for most of the computer time involved in an ETARA simulation. Figure 4 illustrates the steps involved in collapsing the RBD of Figure 1.

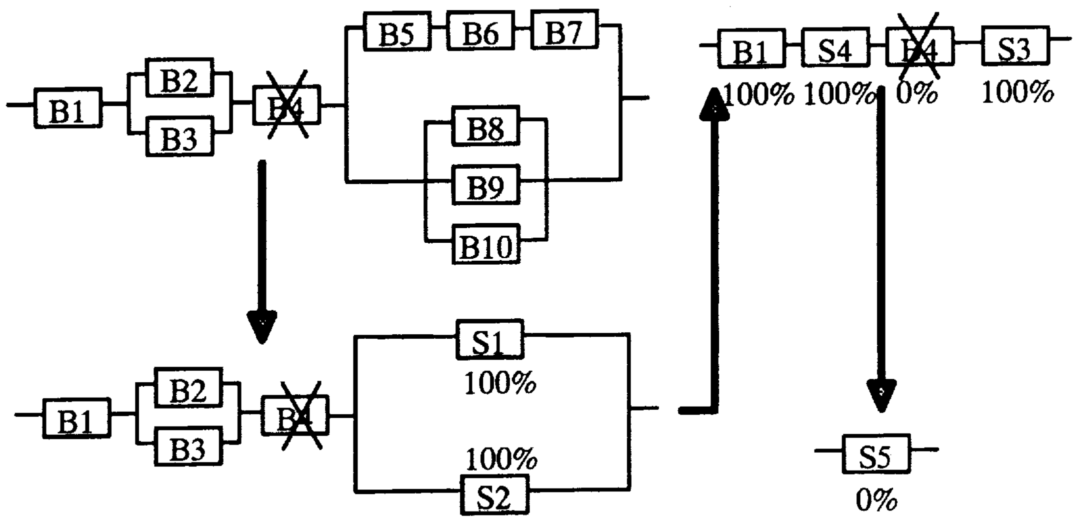


Figure 4 – "Collapsing " the RBD

For discussion, assume that event 1) in figure 3 has just occurred: block 4 has failed. Collapsing the RBD for this event begins with the determination of the status of subsystem 1. Since blocks 5, 6, and 7 are at 100%, subsystem 1 is reduced to a single block, denoted S1, operating at 100%. Next, subsystem 2 is reduced to a single block, S2, at 100% since blocks 8, 9, and 10 are all available. Subsystem 3 is a parallel combination of subsystems 1 and 2 and is therefore also at 100%. Subsystem 4 is at 100%. Finally, the status of subsystem 5, which represents the entire system, is determined by finding the minimum of the capacities of blocks 1 and 4 and subsystems 3 and 4. Since the precipitating event was the failure of block 4 reducing it to 0% capacity, whereas block 1 and subsystems 3 and 4 are at 100%, the total system capacity due to the occurrence of this event is found to be 0%.

The process described above is repeated for each event, whether it is a block failure or repair, to determine the system's output capability after each event. This process accounts for most of the computer time involved in an ETARA simulation.

APPENDIX A

An ETARA Application: "Duplicate Blocks"

This appendix describes the specific application of ETARA to a problem where a given block appears more than once in a system RBD. In traditional deterministic RBD modeling, this is not allowed since the "collapsing" of the RBD will lead to erroneous system reliability and availability results. Collapsing an RBD with "duplicate blocks" is possible in ETARA due to the fact that ETARA simulates failures and repairs of individual blocks and the way in which the subsystem RBD equations are solved.

Figure 5 depicts a situation where the system RBD contains multiple occurrences of block 4.

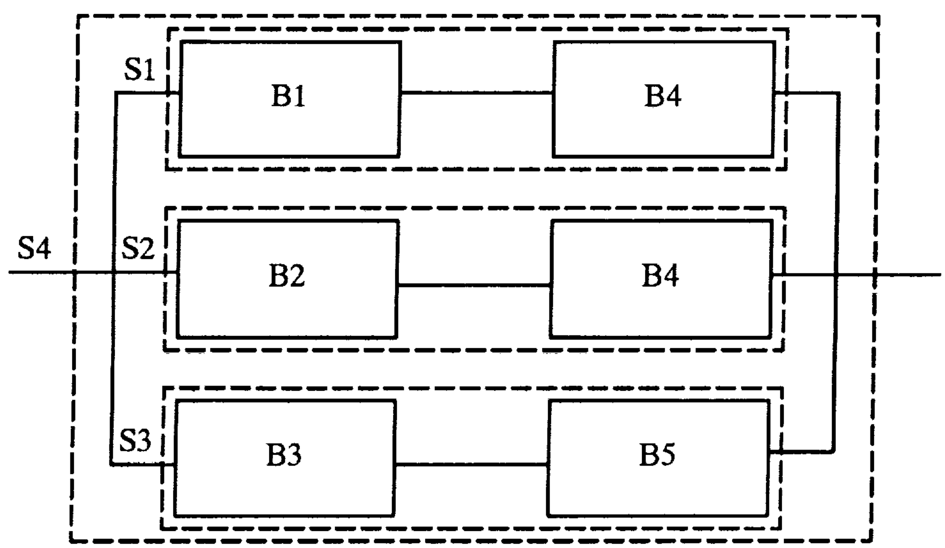


Figure 5 – RBD containing multiple occurrences of block 4

In this simple example, the interdependencies of blocks 1, 2 and 4 can be modeled without multiple occurrences of block 4, as shown in figure 6.

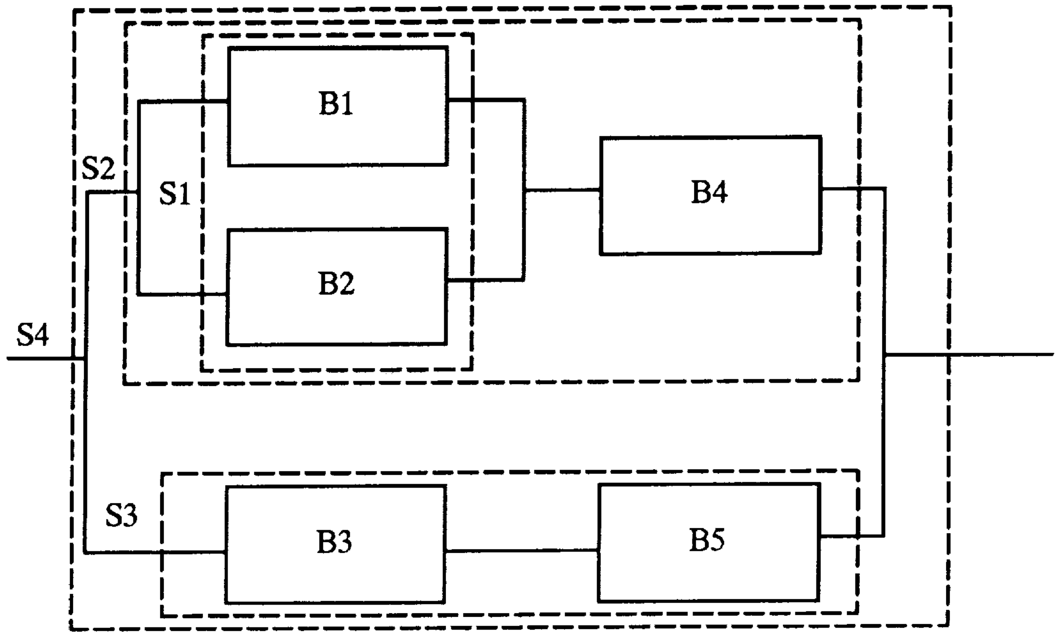


Figure 6 – Same system as figure 5 without "duplicate" blocks

Both figures are equivalent models for the behavior of the same simple 5 block system. All blocks have the same data; 100% capacity, MTBF (exponential) of 2 years, and a MTTR of 2,200 hours. To keep this example simple, a large number of local spares (9999) are defined. This has the effect of restraining the block down time to the MTTR of 2,200 hours without spares replenishment considerations.

The deterministic equations for subsystem and system reliability for the RBD of figure 6 using standard series/parallel reliability mathematics are,

$R_{s1} = 2R - R^2$

$R_{s2} = R_{s1} \times R$

$R_{s3} = R^2$

$R_{s4} = R_{system,\ fig\ 6} = R_{s2} + R_{s3} - (R_{s2} \times R_{s3})$

$R_{system,\ fig\ 6} = R^5 - 2R^4 - R^3 + 3R^2$

The "R" in the above equations is the block reliability. The reliability after 1 year is evaluated by calculating the block reliability as,

$R_{block} = R = \exp[-1/2] = 0.607$

Giving a system reliability after 1 year,

$R_{system,\ fig\ 6} = 0.692$

Now, deterministic equations for subsystem and system reliability for the RBD of figure 5, containing the double occurrence of block 4, assuming standard series/parallel reliability mathematics can be written as,

$R_s = R_{s1} = R_{s2} = R_{s3} = R^2$

$R_{s4} = R_{system,\ fig\ 5} = R_s^3 + 3R_s^2(1 - R_s) + 3R_s\,(1 - R_s)^2$

with a reliability after 1 year,

$R_{system,\ fig\ 5} = 0.747$

This result shows the error in applying standard series/parallel reliability mathematics (or in using software which is based on the standard mathematics) to the RBD of figure 5. Writing the equations in this manner fails to recognize that block 4 in subsystem 1 is duplicated in subsystem 2, giving the appearance of three redundant paths for system success when there are only two, and an overly optimistic 1 year reliability result.

ETARA can correctly calculate the reliability of the system of figure 5 owing to its simulation of individual block failures and sequential collapsing of the system RBD, subsystem by subsystem, from the inside out. The RBD of figure 5 was defined in ETARA and 1,000 simulations of "Reliability with No Repair" were performed over a 1 year duration. The resulting simulated reliability was 0.705, which compares closely to the correct deterministic calculation of 0.692.

ETARA can correctly handle multiple block occurrences in an RBD for both availability and reliability simulations. In the example discussed above, it would be preferable to use the RBD of figure 6 primarily for the sake of clarity and conciseness. However, many real–life situations arise where duplication of blocks in an RBD is unavoidable due to functional dependencies, cross–strapping of components, and operational redundancy. A good example is the high degree of cross–strapping and switching to redundant pathways in a power distribution operation. With this capability, ETARA greatly extends the applicability of RBD modeling.

APPENDIX B

The Data Input Full Screen Editor

This appendix contains instructions for using the data input full screen editors. These instructions may be viewed during the editor session by pressing the Help key, [F1]. The help window disappears upon pressing [Escape]. The "Function Key" numbering and corresponding keystrokes are as follows:

Function Key Number	Keystrokes
F1 - F10	[F1] - [F10]
F11 - F20	[Shift]/[F1] - [F10]

Quit Editing Session
To quit the editing session without saving the changes you made, press [Escape].

Save Editing Session
To exit the editing session and save these changes, press [Enter].

Cursor Movement
Use the [Tab] key to move the cursor to the right from one column to the next. Use [Shift]/[Tab] to move the cursor left to the previous column. Press the "Large Plus", [+], key to jump to the next line of the table. Press [F5] to jump to the top row of the table. Press [F6] to jump to the bottom row of the table.

Restore Original Data to Screen
To restore the original contents at the cursor position, press [F3]. Press [Shift]/[F3] to restore the entire row.

Insert a Row
To insert a row on the screen, place the cursor one line below where the new line is to be located and press [F8]. At the prompt, type in the number of rows to be inserted and press the [Enter] key.

Toggle between Replace and Insert Modes
At the beginning of an edit session, you will be in Replace mode, in which keystrokes will write over the previous text. The editor can also operate in Insert mode, in which the keystrokes will move existing text to the right. To switch from one mode to the other, press the [Insert] key.

Mark/Unmark Rows
To **mark** rows of the table for copying, moving, deleting or saving, move the cursor to each of the desired rows and press [Shift]/[F9]. Each of the rows will be highlighted. Marked

(highlighted) rows may be copied, moved or deleted. To **unmark** a row, move the cursor to that row and press [Shift]/[F9]. To mark or unmark **all** rows, press [Shift]/[F10].

Delete Rows
To delete a row, place the cursor on the row to be deleted and press [Shift]/[F8]. If any rows are marked (highlighted), these rows will be deleted.

Copy Rows
To copy a row of the table, move the cursor to the row and press [F10]. If any rows are marked (highlighted), these rows will be copied.

Save Rows
To save rows of the table for later use, mark the rows (see the paragraph above entitled **Mark/Unmark Rows**), press [Shift]/[F6] and enter a name for this group of rows.

Retrieve Saved Rows
Rows saved as described above can be retrieved into an editing session by pressing [Shift]/[F5] at the cursor and entering a name.

Discard Saved Rows
To discard a set of rows, press [Ctrl]/[F6].

Print
To use the printer while in an editor session, press [F2]. The following options will be available with a single keystroke:

[G] 'Go': Prints any marked rows. If no rows are marked, the entire table will be printed.

[R] Resets line counter to 0. This aligns the printer to the top of the page.

[L] Advance the printer 1 line.

[P] Advance the printer 1 page.

APPENDIX C

Hardware and Software Requirements

ETARA requires the IBM APL2 programming language on a 80386 based microcomputer with a 80387 math coprocessor or an 80486 based microcomputer and at least 2 megabytes of extended memory. DOS 3.3 or higher is required for the operating system. APL2 for the PC is available from:

IBM Direct
Phone: 800–IBM–2468
Part Number 6242936

ETARA is provided on 5.25 inch. high density floppy diskettes containing the following three files:

etara.atf

example_.esf

example_.erf

The two "example" files can be read from within ETARA and contain the system configuration and analytical results from the example given in Appendix X.

Installation and Execution Instructions

To install, copy the ETARA workspace, "etara.atf", to the system APL2 directory, with the DOS "copy" command. Next, enter the APL2 system. It should be noted that ETARA requires eight auxiliary processors. An example invocation would be:

apl232 ap2 ap80 ap100 ap101 ap103 ap124 ap206 ap210

ETARA can now be loaded from its transfer–format file with the command:

)IN ETARA

From here, the user may examine or modify any of the ETARA code. To begin execution of ETARA, the main function is called by typing:

ETARA

APPENDIX X

An ETARA Example

This appendix illustrates how the user would work through the ETARA menus in order to define the example system depicted in figure 1. The keystrokes and data which the user must enter are illustrated in **boldface type** in the following example. This appendix should be used in conjunction with section 3.0 of this manual which discusses the ETARA menus in detail.

X 1.0 System Definition

Generally, two types of information are necessary in defining a system. One is the block data and the other is the reliability block diagram (RBD). To define this information in the order in which the ETARA menus are set up, the user first enters block data via the BLOCK DATA INPUT menu. From the ETARA MAIN MENU, the user selects "System definition; Enter or modify data; **B**lock data, numbers, initial ages and installation times"; (Keystroke sequence **S–E–B**). At this point, the BLOCK DATA INPUT menu is displayed,

BLOCK DATA INPUT

Data by type

Numbers for each type

Ages at beginning of simulation

Installation times

eXit

The user must enter data for the first two selections on this menu. If data is not entered for the Ages and Installation time selections, ETARA defaults to "zero" for both. This means that all blocks will be new (zero initial age) and will be installed and active (zero installation time) at the beginning of the simulation. On pressing **D**, the Block Data editor is displayed;

Name	Capacity (%)	MTBF, Yrs (Random)	Mean Life,Yrs (Wearout)	MTTR, hrs.	Shape Factor	Local Spares	Depot Spares
type 1	**100**	**99999**	**10**	**48**	**3.44**	**1**	**9999**
type 2	**75**	**8**	**99999**	**24**	**1**	**0**	**9999**
type 3	**50**	**15**	**7**	**6**	**4.12**	**3**	**9999**
type 4	**0**	**50**	**3**	**52**	**3.44**	**0**	**9999**

The user enters **block type** data in this editor, illustrated in **bold.** Note that even though the RBD of figure 1 has ten individual blocks, in this example as defined above, there are only four types of blocks. When the block type data entries are complete, the user presses **[Enter]** to save the information and leave the editor. ETARA then returns to the BLOCK DATA INPUT menu.

Working down this menu, the next choice is "Numbers for each type". On pressing **N**, the Block Number editor is displayed;

Type	Block Numbers
type 1	**1 4**
type 2	**2 3**
type 3	**5–7**
type 4	**8–10**

The user assigns **block numbers** to the different block types. In the example, block numbers 1 and 4 in the RBD are of block type 1; blocks 2 and 3 are of type 2; blocks 5 through 7 are of type 3; and blocks 8 through 10 are of type 4. When the block number data entries are complete, the user presses **[Enter]** to save the information and leave the editor. ETARA again returns to the BLOCK DATA INPUT menu.

As mentioned, the "Ages at the beginning of simulation" selection is optional. If chosen, pressing **A** will bring up an editor in which the user assigns initial ages to individual blocks via the block's number;

Age, Yrs	Block Numbers
1	**1**
3	**4**

Here, initial ages of 1 year for block 1 and 3 years for block 4 have been assigned. Since no other initial age assignments are made, ETARA defaults to a zero initial age for the remaining blocks. The user presses **[Enter]** to save the information and leave the editor.

The final selection, "Installation times", is also optional. Pressing **I** brings up an editor in which the user assigns installation times to individual blocks;

Install. Time, yr.	Block Numbers
.25	2

The above input indicates that block 2 will be installed 3 months (year 0.25) after the beginning of the simulation. All other blocks will be installed and active at year 0, the beginning of the simulation. Reviewing the block data shows that block 2 has a 75% capacity and is part of a simple parallel arrangement in subsystem 4. Since block 2 is not present from the beginning of the simulation until the end of the third month (year 0.25), subsystem 4 will only be able to contribute the 75% capacity of block 3. This means the system's maximum capacity will only be 75% of its total capacity until block 2 is installed and the system is complete. ETARA availability results are normalized to the maximum possible output capacity during a given time period. Since 75% capacity is the maximum possible during the first three months, ETARA bookeeps occurrences of the 75% output state under the 100% category during this period. Therefore, the availability results for this example for the 100% state will include those occurrences of the 75% state during the first three months. Press **[Enter]** to save the information and leave the editor. This completes the block data input. Pressing **X** will return the user to the DATA INPUT menu.

DATA INPUT

Block data, numbers, initial ages and installation times

Reliability block diagram

Parameters of the simulation

e**X**it

The user can now move on to the Reliability Block Diagram (RBD) definition. From the DATA INPUT menu, the **R**eliability block diagram selection brings up the RELIABILITY BLOCK DIAGRAM MENU screen. The user then selects the **E**nter reliability block diagram choice which brings up the RBD editor;

			M of N Data	
Sub #	Type	Elements	Min #	Capacity
1	s	b5–7		
2	b	b8–10	2	50
3	p	s1 2		
4	p	b2 3		
5	s	b1 4 s3 4		

The input data which defines the RBD of figure 1 on page 2 is shown above. Note that subsystem 2 is a parallel 2–of–3 binary arrangement in which 2 or more blocks must be available for the subsystem to contribute 50% of the total system capacity. If less than 2 blocks are available, then subsystem 2 is at 0% capacity. Press **[Enter]** to save the information and leave the editor. Select e**X**it to return once again to the DATA INPUT menu.

Now, the example system has been defined in terms of an RBD and block data. The remaining selection from the DATA INPUT menu allows the user to define the **P**arameters of the simulation.

SIMULATION PARAMETERS

Duration, number of runs, spares resupply

Minimum capacity for reliability

Probability of exceedence

e**X**it

This example will illustrate the definition of an availability simulation with probability of exceedence statistics. Selection **D** brings up the following field editor;

Duration	30	(Years)
Number of Runs	10	
Local Spares Replenishment Interval	90	(Days)
Resupply Cutoff	30	(Days)
Depot Spares Replenishment Interval	365	(Days)

Here, the user has stipulated that the system's behavior over 30 years (duration) will be simulated. Ten (number of runs) separate simulations will be performed from which the statistical results will be calculated. If no local spares are available, they will be delivered from the depot on 90 day intervals, subject to a 30 day cutoff. This means that if a spare block is needed 30 days or less from a scheduled delivery, that spare block must wait until the following delivery. The depot spare stock will be replenished every year (365 days). **[Enter]** is pressed to save the information, leave the editor and return to the SIMULATION PARAMETERS menu.

Since the user is defining an availability simulation, the **M**inimum capacity for reliability choice is skipped. After selecting **P**robability of exceedence from the SIMULATION PARAMETERS menu, the user is presented with two further choices. The "**M**ultiple capacity level data" choice will be illustrated.

Probability of Exceedence Data

Time, yrs	Capacity levels
0–30, 1	0–100, 25

Here, the user has stipulated that in one year increments throughout the 30 year duration, ETARA will take a "snap shot" of the system and track whether or not the system's output capacity at that point in time exceeds 0, 25, 50, 75 and 100% (0 through 100 in increments of 25). At the end of the set of 10 runs of 30 years of simulated system behavior, the probability that the system's capacity met or exceeded 0, 25, 50, 75 and 100% capacity at each year through the duration will be reported based on information averaged over the 10 runs. **[Enter]** is pressed to save the information, leave the editor and return to the SIMULATION PARAMETERS menu.

At this point, the user has defined the RBD, block data and simulation parameters. The user now presses **X** twice to return to the SYSTEM DEFINITION menu. The "**F**ile management" choice is selected so that this newly–defined system can be saved in a system configuration file. After the file is saved, **X** is pressed to return to the ETARA MAIN MENU. The user then selects "**R**un simulation", followed by "**A**vailability" to begin the simulation.

X 2.0 Results Analysis

The results illustrated in this section are what is obtained on running an Availability simulation using the system as defined in section X 1.0. The 10 availability simulation runs of a 30 year duration for the 10 block system illustrated here took 2 minutes and 23 seconds on a DELL 386 PC at 20 Mhz with a math co–processor.

To obtain a menu from which the availability results can be displayed, the user selects "Analyze results" from the ETARA MAIN MENU followed by "Availability results" from the "SIMULATION RESULTS ANALYSIS" menu;

AVAILABILITY RESULTS ANALYSIS

System availability

Block availability

Continuous state behavior

Probability of exceedence

eXit

From this menu, the user can select from a variety of availability result displays. Each selection is illustrated in the following pages. After viewing each of the results displays, the user presses **[Enter]** and is returned to the above menu.

"System availability", followed by "Tabular results";

SYSTEM CAPACITIES AND AVAILABILITIES

System Capacity States	Time at Each Cap. State, Yrs	Availability of Each Capacity St.	Availability of Capacity St. or Greater	Equivalent Availability
1 100.0	25.06895	.83563	.83563	.83563
2 75.0	1.18276	.03943	.87506	.02957
3 50.0	2.71905	.09063	.96569	.04532
4 0.0	1.02924	.03431	1.0000	.00000
SUMMATION	30.00000	1.0000		.91052

The 100% state results include the occurrence of the 75% state during the first three months of the system's simulation, since it was the maximum output capacity obtainable do to block 2 not being installed.

"System availability", followed by "Graphics display";

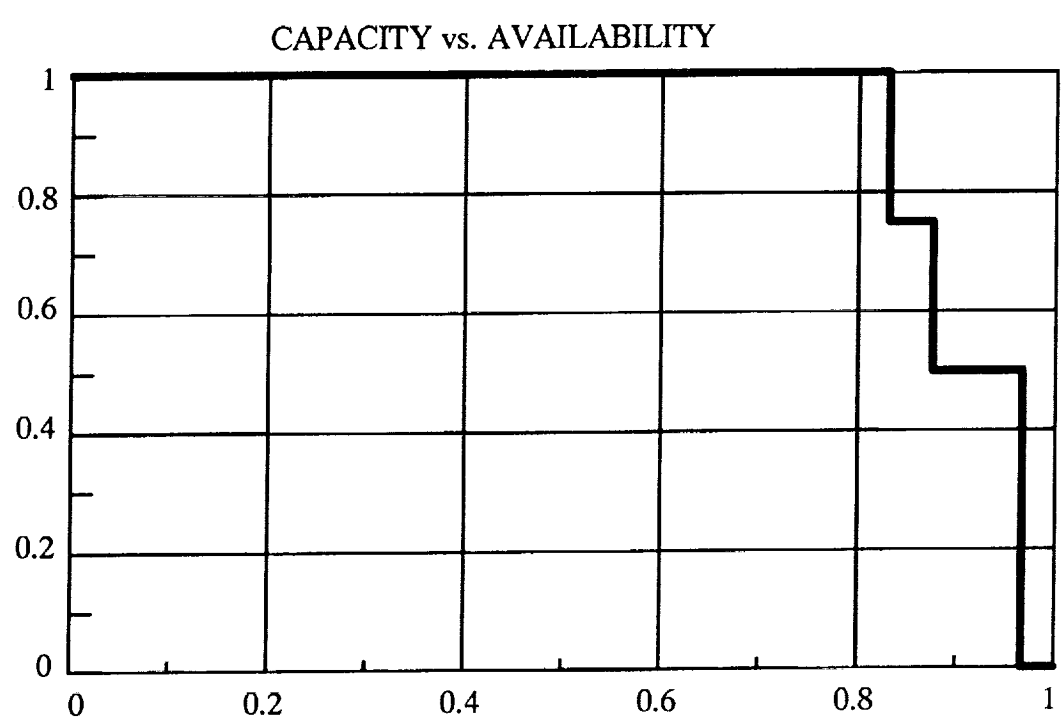


Figure 2 – Graph of System Capacity (y–axis) vs. Availability (x–axis)

"**B**lock availability", followed by "**I**ndividual";

INDIVIDUAL BLOCK FAILURE AND REPAIR RESULTS

Block Name	No.	# Of Failures Raw	Per Dura	Downtime, Yrs. Raw (Years)	Per Dura (Days)	% Dura	Delay Time Raw (Years)	Per Dura (Days)
type_1	1	30	3.00	5.6	205.160	1.87	5.5	199.337
type_2	2	38	3.80	8.3	303.318	2.77	8.2	299.657
type_2	3	37	3.70	7.5	273.027	2.49	7.4	270.917
type_1	4	24	2.40	4.0	146.683	1.34	3.9	141.639
type_3	5	51	5.10	8.0	293.494	2.68	8.0	292.225
type_3	6	50	5.00	7.5	272.189	2.49	7.4	270.917
type_3	7	49	4.90	10.0	366.053	3.34	10.0	364.737
type_4	8	87	8.70	17.8	650.507	5.94	17.3	631.503
type_4	9	92	9.20	20.3	739.620	6.75	19.7	720.185
type_4	10	92	9.20	19.2	701.329	6.40	18.7	681.287

"**B**lock availability", followed by "by **T**ype";

BLOCK TYPE FAILURE AND REPAIR RESULTS

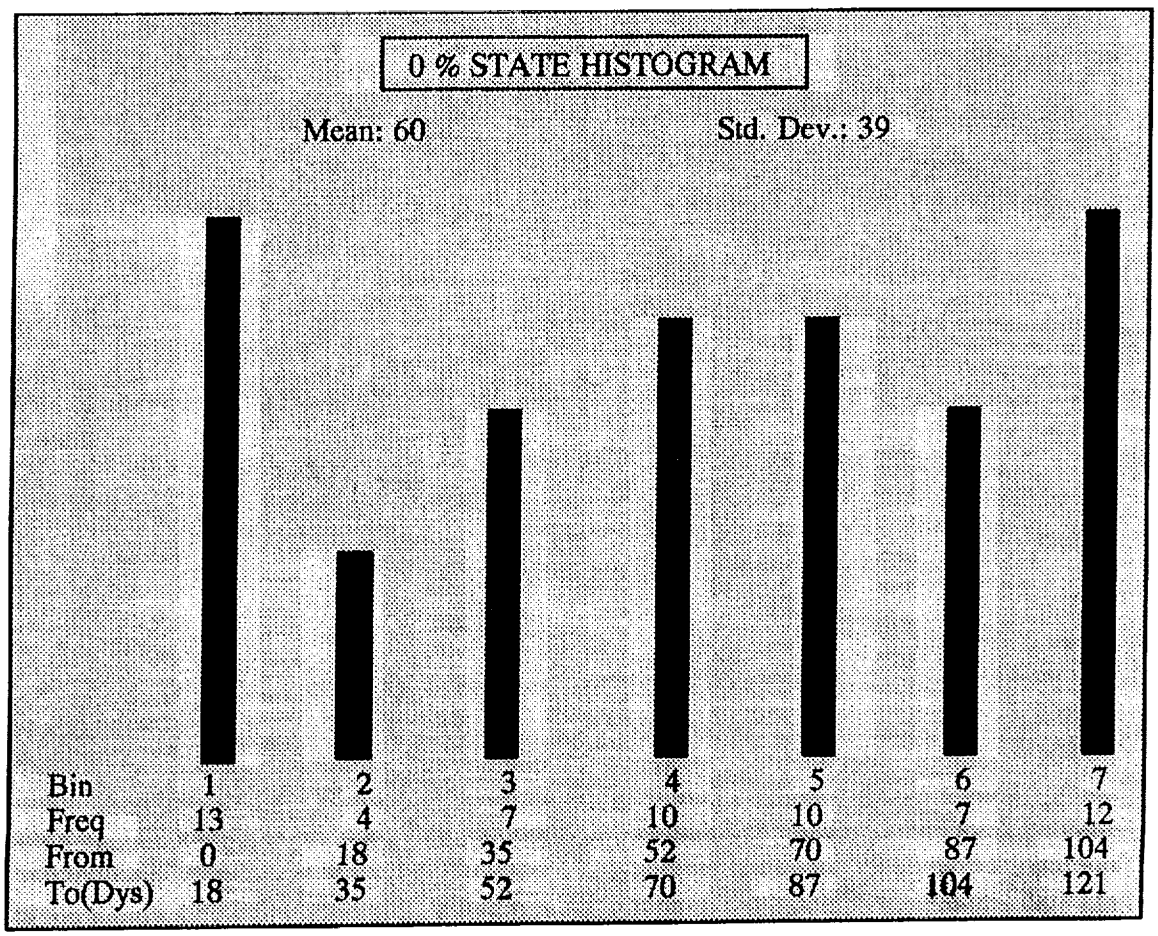
Block Type Name	Quant	# of Failures Per Dura	Year	Repair Time Per: Dura (Days)	Year (Hours)	% Of Total Repair Time	Down Time	Delay Time
type_4	3	27.10	.90	58.48	46.79	72.43	52.93	52.52
type_3	3	15.00	.50	3.86	3.09	4.78	23.58	23.97
type_2	2	7.50	.25	7.54	6.03	9.33	14.59	14.70
type_1	2	5.40	.18	10.87	8.69	13.46	8.90	8.81

"Continuous state behavior", followed by "Tabular results";

AVERAGE CONTINUOUS STATE TIME FOR EACH CAPACITY

System Capacity States	Time at Each Cap. State, Yrs	Availability of Each Cap. State	Average Continuous State Time	Average Num. of Occurrences Per Duration
1 100.0	25.06895	.83563	349.24298	26.2000
2 75.0	1.18276	.03943	53.29721	8.1000
3 50.0	2.71905	.09063	58.03816	17.1000
4 0.0	1.02924	.03431	59.63079	6.3000
SUMMATION	30.00000	1.00000		

"Continuous state behavior", followed by "Histograms", followed by "Zero capacity";



"Probability of exceedence";

PROBABILITY OF EXCEEDENCE

Capacity		Time, yrs .00	1.00	2.00	3.00	4.00	5.00
1	0.0	1.0	1.00	1.00	1.00	1.00	1.00
2	25.0	1.0	1.00	1.00	1.00	1.00	1.00
3	50.0	1.0	1.00	1.00	1.00	1.00	1.00
4	75.0	1.0	1.00	1.00	1.00	1.00	.90
5	100.0	.00	1.00	1.00	.00	1.00	.90

Probability of exceedence results for years 6 through 30 can be viewed by pressing the "right arrow" key.

This completes the illustration of availability results for the example under consideration. Since an Availability simulation was performed, Maintainability results can also be displayed. This is done by selecting "Maintainability results" from the "SIMULATION RESULTS ANALYSIS" menu. The illustration appears on the next page.

MAINTENANCE MAN-HOURS PER YEAR		
Year	Mean, Hours	Std. Dev., Hours
1	5.40	12.49
2	37.22	25.77
3	45.47	37.85
4	55.42	41.08
5	78.61	70.59
6	50.23	40.78
7	72.33	41.97
8	95.75	53.78
9	50.92	43.84
10	75.08	69.20
11	87.41	53.68
12	44.92	31.12
13	45.66	46.07
14	83.58	40.74
15	50.61	36.78
16	94.35	46.40
17	66.86	48.10
18	66.10	43.44
19	95.16	64.53
20	85.05	47.13
21	67.28	26.14
22	56.31	33.53
23	73.36	44.76
24	57.38	30.05
25	65.24	32.99
26	68.20	50.50
27	77.99	50.74
28	43.83	56.34
29	83.47	70.15
30	58.59	60.86
30 Year Ave. =	64.59	19.8

The results from the availability simulation can be saved via the "File management" selection from the "SIMULATION RESULTS ANALYSIS" menu.

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15. Supplementary Notes

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16. Abstract

This document is a user's manual describing an interactive, menu-driven, personal computer based Monte-Carlo reliability, availability, and maintainability simulation program called ETARA (Event Time Availability Reliability Analysis). Given a Reliability Block Diagram representation of a system, ETARA simulates the behavior of the system over a specified period of time using Monte-Carlo methods to generate block failure and repair intervals as a function of exponential and/or Weibull distributions. Availability parameters such as equivalent availability, state availability (percentage of time as a particular output state capability), continuous state duration and number of state occurrences can be calculated. Initial spares allotment and spares replenishment on a resupply cycle can be simulated. The number of block failures are tabulated both individually and by block type, as well as total downtime, repair time, and time waiting for spares. Also, maintenance man-hours per year and system reliability, with or without repair, at or above a particular output capability can be calculated over a cumulative period of time or at specific points in time.

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