NUREG-0193

FRANTIC - A COMPUTER CODE FOR TIME DEPENDENT UNAVAILABILITY ANALYSIS

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FRANTIC - A COMPUTER CODE FOR TIME DEPENDENT UNAVAILABILITY ANALYSIS

W. E. Vesely
F. F. Goldberg

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Probabilistic Analysis Branch
Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

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ABSTRACT

The FRANTIC computer code evaluates the time dependent and average unavailability for any general system model. The code is written in FORTRAN IV for the IBM 370 computer. Non-repairable components, monitored components, and periodically tested components are handled. One unique feature of FRANTIC is the detailed, time dependent modeling of periodic testing which includes the effects of test downtimes, test overrides, detection inefficiencies, and test-caused failures. The exponential distribution is used for the component failure times and periodic equations are developed for the testing and repair contributions. Human errors and common mode failures can be included by assigning an appropriate constant probability for the contributors. The output from FRANTIC consists of tables and plots of the system unavailability along with a breakdown of the unavailability contributions. Sensitivity studies can be simply performed and a wide range of tables and plots can be obtained for reporting purposes. The FRANTIC code represents a first step in the development of an approach that can be of direct value in future system evaluations. Modifications resulting from use of the code, along with the development of reliability data based on operating reactor experience, can be expected to provide increased confidence in its use and potential application to the licensing process.

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A. THE BASES FOR THE FRANTIC CODE

1. INTRODUCTION

In WASH-1400 [1], system unavailabilities were calculated in order to predict the accident sequence probabilities and the corresponding accident risks. The system unavailabilities which were applicable for the WASH-1400 predictions were the average system unavailabilities, averaged over a one year time period.

In addition to the average unavailability, the time dependent, instantaneous unavailability can also be important in probabilistic evaluations. If q(t) represents the time dependent instantaneous unavailability, then the average unavailability $\bar{q}$, as computed in WASH-1400, is given by

$$\bar{q} = \frac{1}{T} \int_0^T q(t)dt \qquad (1)$$

where T = one year. By definition the instantaneous unavailability q(t) is the probability that the system is unavailable at the given instant of time t. The quantity $\bar{q}$ is the average fraction of time that the system is down.

To illustrate the roles of $\bar{q}$ and q(t) in probabilistic analyses, consider a particular accident sequence consisting of one initiating event and one system which is called upon to operate. Let Λ be the constant occurrence rate for the initiating event. The probability f(t)dt that the accident sequence will occur in some time interval dt at time t is

$$f(t)dt = \Lambda\, q(t)dt \qquad (2)$$

and hence $\Lambda q(t)$ is the instantaneous accident frequency, i.e., the probability of an accident occurring per unit time at time t.

The yearly accident frequency P, which is what WASH-1400 computed, is the integral of $\Lambda\, q(t)dt$ over a one-year period T;

$$P = \int_0^T \Lambda\, q(t)dt = T \frac{1}{T} \int_0^T q(t)dt, \qquad (3)$$

or

$$P = \Lambda T \bar{q}, \qquad (4)$$

From Equation (2) the instantaneous unavailability q(t) thus enters into the instantaneous accident frequency rate $\Lambda\, q(t)$ and from Equation (4) the average unavailability $\bar{q}$ enters into the yearly accident probability $\Lambda T \bar{q}$.

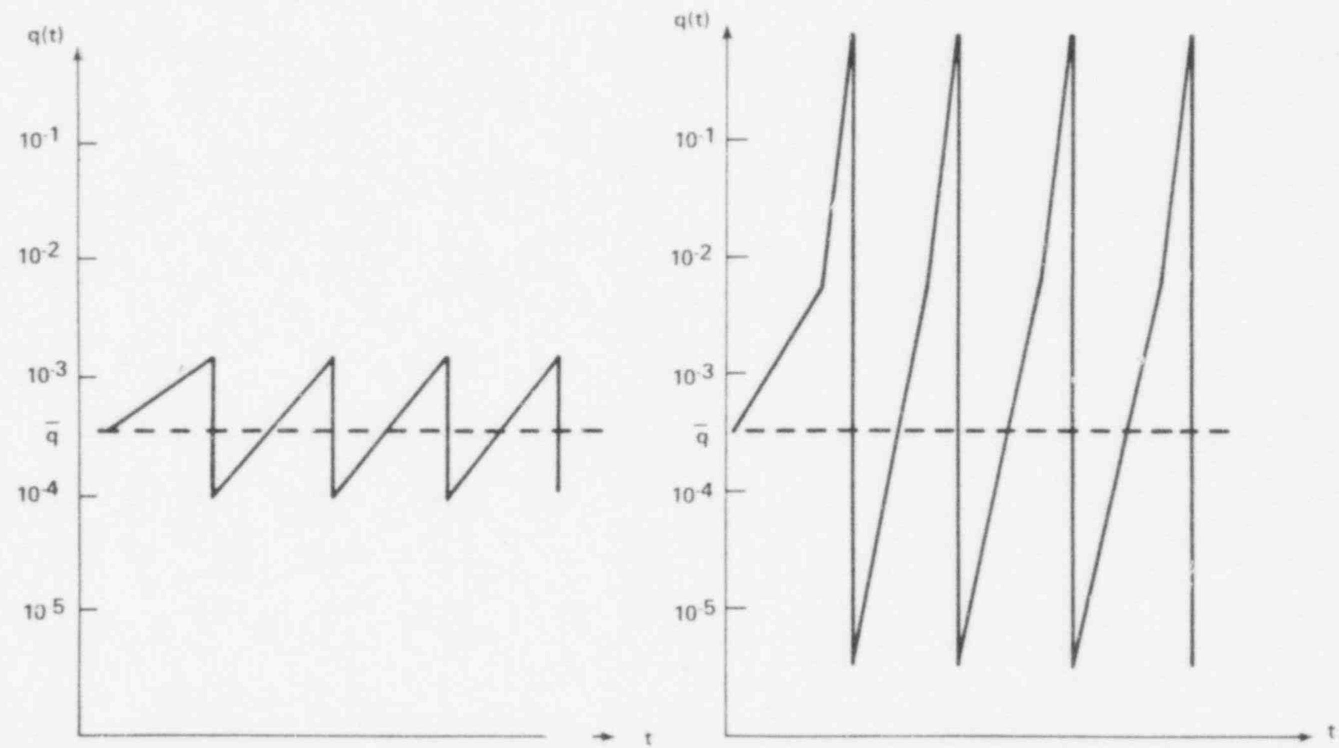
The instantaneous accident frequency $\Lambda\, q(t)$ describes the detailed time behavior of the accident likelihood. The time at which $\Lambda\, q(t)$ is a maximum, i.e., the time at which the instantaneous system unavailability q(t) is a maximum, is the time at which the accident is most likely to occur. A safety system may have a low average unavailability $\bar{q}$ and yet at particular times the instantaneous unavailability q(t) may be quite high indicating the plant is most vulnerable to accidents at these times. Figure A-1 shows two systems which have the same average unavailability but which have quite different instantaneous unavailabilities. The system with the higher unavailability "peaks" in q(t) is a more loosely controlled system and, with regard to having higher instantaneous unavailabilities, is the poorer system. In assessing system design or system operation, the instantaneous unavailability q(t), particularly the maxima, or "peaks" in q(t), may therefore be examined, along with the average unavailability $\bar{q}$, for a more complete evaluation.

2. THE PURPOSE OF THE FRANTIC CODE

The FRANTIC computer code was developed to calculate both the instantaneous unavailability and the average unavailability of a system and to give a breakdown of the unavailability contributions from failures, testing, and repair. Accident sequences, such as constructed from event trees, can also be evaluated for their instantaneous and average probability behavior. The name "FRANTIC" is an acronym for Formal Reliability Analysis including Normal Testing, Inspection and Checking. The FRANTIC code represents one extension of the probabilistic methodology described in WASH-1400.

Figure A-1

Two Systems with the Same Average Unavailability
($\bar{q}$) but with Different Instantaneous Unavailabilities (q(t))



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The FRANTIC code was developed to investigate periodic testing schemes and operational and design modifications as they affect system unavailabilities and accident probabilities. Testing characteristics which can be input to FRANTIC include the test interval, the test duration time, the repair time or allowed downtime, the test override capability, the test efficiency, and human-caused failure probabilities associated with the test. The system logic which is input to FRANTIC can be easily changed to investigate the impacts of operational and design modifications.

The present version of the FRANTIC code uses the exponential failure distribution to describe hardware failures. The constant component failure rates can be changed to investigate the effects of different hardware reliabilities. In addition to the hardware contribution, the system models can also include human error and common cause contributions. The subsequent sections will describe the unavailability equations used in the FRANTIC calculations and will give the input required for the code as well as the output which is produced.

3. TYPES OF COMPONENTS CONSIDERED BY FRANTIC

3.1 Basic Definitions

Four types of components are handled by the FRANTIC code, constant unavailability components, nonrepairable components, monitored components, and periodically tested components. By definition, a constant unavailability component is described by a per demand (or per cycle) unavailability which is independent of time. A nonrepairable component is one which, if it fails, is not repaired during plant operation. A monitored component is a component in which the failure is immediately detected and repair is then begun; the detection device can be an alarm, annunciator, or any other signaling means. A periodically tested component is one in which tests are performed at regular intervals, such as every 30 days, and any failure of the component is not detectable until the test is performed.

3.2 Constant Unavailability Components

The unavailability q for this type of component is given by

$$q = q_d \tag{5}$$

where q_d is the per demand unavailability, input by the user. Cyclic unavailabilities can be modeled in this manner, where the unavailability is time-independent and depends only on the cycle or demand. Human errors (per demand) can also be modeled in this way using the appropriate value for q_d.

3.3 Nonrepairable Components

Assuming an exponential distribution, as done in FRANTIC, the instantaneous unavailability for a nonrepairable component q(t) is given by

$$q(t) = 1 - \exp(-\lambda t) \tag{6}$$

$$\cong \lambda t \tag{7}$$

where λ is the component failure rate. The approximation given by Equation (7) is used in FRANTIC and is accurate to within 5% for unavailabilities less than 0.1. The approximation is slightly conservative.

3.4 Monitored Components

For a monitored component, the instantaneous unavailability quickly approaches a constant asymptotic value and the asymptotic value is used in FRANTIC[2]. The asymptotic unavailability q is given by

$$q = \frac{\lambda T_R}{1 + \lambda T_R} \tag{8}$$

$$\cong \lambda T_R \tag{9}$$

---

[2]The asymptotic value is achieved after a time period of approximately $3T_R$ into operation.

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where λ is again the component failure rate and T_R is the average repair time [2]. The average repair time should also include the time from detection to the beginning of repair.

It is important that a statistical average repair time be used for T_R which may entail averaging over a repair time distribution. The approximation given by Equation (9) which is used in FRANTIC, is slightly conservative and is accurate to within 10% if the unavailability is less than 0.1. If certain failure modes are not detectable by the monitoring device, then the appropriate fraction of failures can be treated as being nonrepairable (using pλ for the nonrepairable component failure rate where p is the detection inefficiency).

3.5 Periodically Tested Components

3.5.1 Basic Equations

Periodically tested components are quite common in safety systems, which are generally standby systems and are not operated until an accident situation occurs. To help ensure that the systems are available if needed, the components are periodically tested to detect any failures which might have occurred during standby. The FRANTIC code contains detailed modeling of the instantaneous unavailability associated with periodically tested components, which includes testing contributions as well as failure contributions.

If testing is assumed to be perfect, then the instantaneous unavailability of a periodically tested component is shown in Figure A-2. The unavailability has the standard sawtooth behavior and increases (approximately) linearly from 0 to λT between the tests of interval T. (The linear approximation is used for the exponential here.)

When testing is not perfect and testing contributions are included, the sawtooth plot will have additional unavailability contributions at the test times. Two types of testing contributions are handled by FRANTIC, a "test downtime contribution" and "a repair contribution." The test downtime contribution arises from the non-zero on-line time required to perform the test. When there is a test override or bypass capability the unavailability will be lowered due to the override capability; however, there will still be a downtime contribution. The repair contribution arises from the non-zero on-line time required to repair the component if it is found failed.

If τ is the average on-line time required to perform the test and T_R is the average repair time, then the periodic tests as modeled in FRANTIC, will have the features shown in Figure A-3. The first interval T_1 is the time from plant startup to the first test. The remaining tests on the component are carried out at intervals of T_2, from start of test to the start of the next test. The first interval T_1 can be the same as T_2 or can be different to account for staggering of tests among different components.

The unavailability will consist of the unavailability between tests and the unavailability during the test period τ and repair period T_R. The unavailability between tests will have the sawtooth behavior. For the first test interval

$$q(t) = \lambda t \qquad 0 \le t \le T_1 \qquad (10)$$

For the second test interval,

$$q(t) = \lambda(t-\tau) \qquad \tau < t \le T_2 \qquad (11)$$

where t is the time from the start of the previous test. For Equation (11), it is assumed that the test detects all failures occurring in the test period τ; in essence failures caused by the test are assumed to be immediately detectable. For test intervals after the second, the unavailability periodically repeats according to Equation (11). Figure A-4 illustrates the between tests unavailability behavior.

To determine the unavailability during the test period and repair period, let Q be the component unavailability immediately before the test begins. From Equation (10) for the first test interval

$$Q = \lambda T_1 \qquad (12)$$

and from Equation (11), for the remaining intervals

$$Q = \lambda(T_2-\tau) \qquad (13)$$

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Figure A-2

Instantaneous Unavailability When Testing Contributions are Ignored

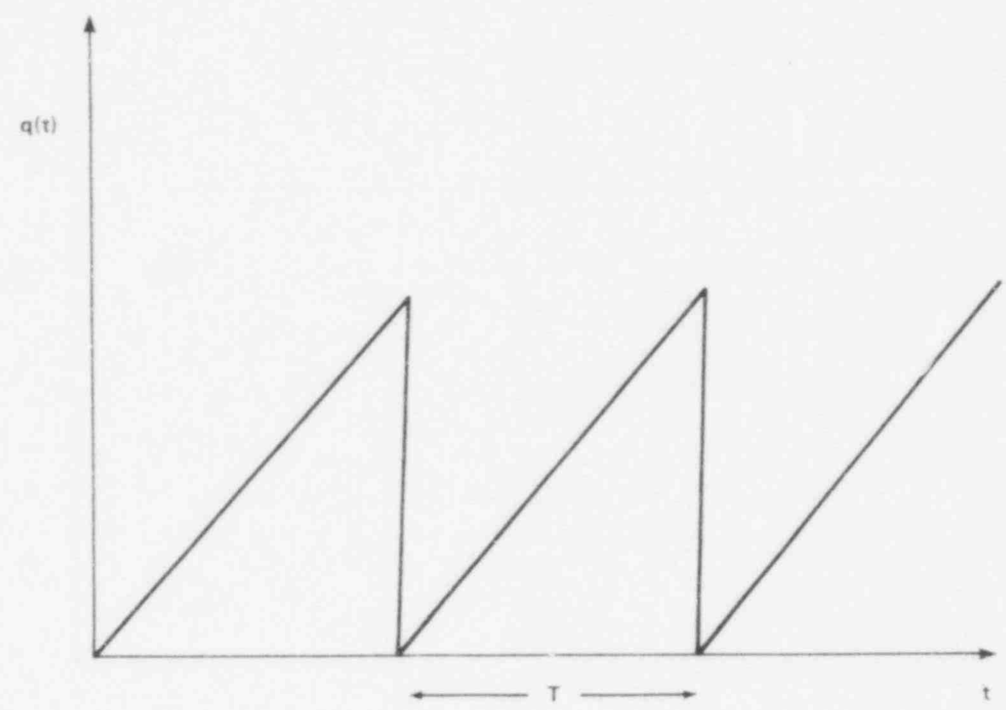

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Figure A-3

Periodic Test Modeling Used in FRANTIC

T_1 = FIRST TEST INTERVAL

T_2 = SECOND AND REMAINING TEST INTERVALS

τ = AVERAGE TEST TIME

τ_R = AVERAGE REPAIR TIME

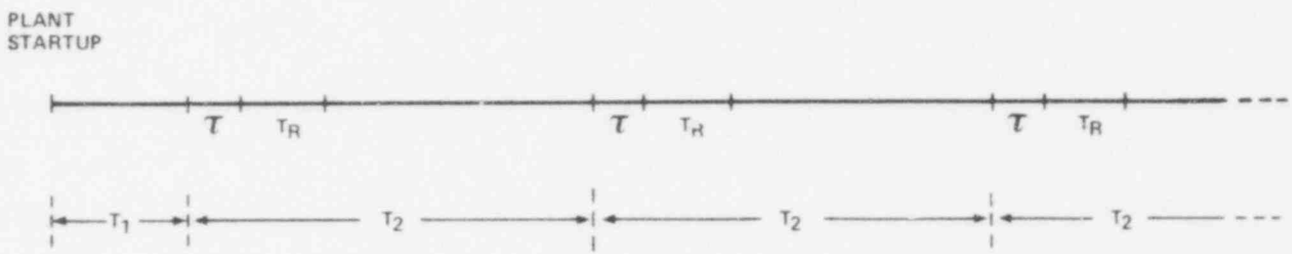

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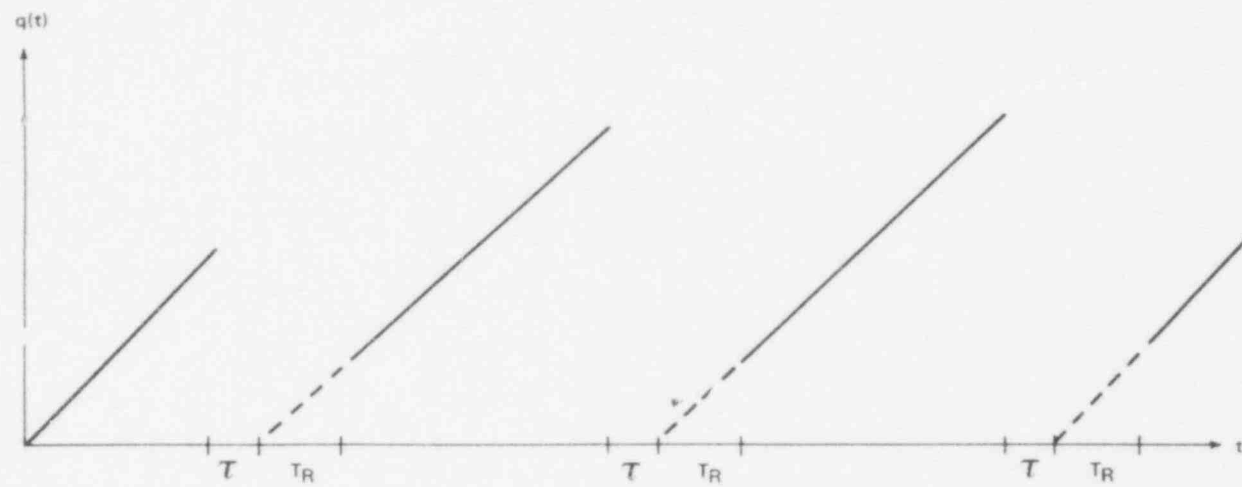
Figure A-4

The Instantaneous Unavailability Between Tests



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The unavailability q_1 during the test period τ and the unavailability q_2 during the repair period T_R are then calculated in FRANTIC from the following formulas:

$$q_1 = p_f + (1-p_f)q_o + (1-p_f)(1-q_o)Q \quad (14)$$

$$q_2 = p_f + (1-p_f)Q + (1-p_f)(1-Q)\tfrac{1}{2}\lambda T_R \quad (15)$$

where

$$p_f = \text{the probability of a test-caused failure} \quad (16)$$

and

$$q_o = \text{the test override unavailability} \quad (17).$$

The term p_f is the probability that the test itself causes component failure and q_o is the probability that the component cannot transfer from a test mode to an operate mode if a demand occurred (the test override capability). As given by Equation (14), during the test period the component can be unavailable due to either of three causes: 1) a test caused failure occurs, with probability p_f, 2) the test cannot be overriden, with probability q_o, or 3) the component has failed between tests, with probability Q. Equation (14) expresses these three contributions in a disjoint manner.

As given by Equation (15), the component can be unavailable during the repair period due to either of three causes: 1) a test-caused failure has occurred requiring repair, with probability p_f, 2) the component has failed between tests again requiring repair, with probability Q, or 3) the component is up but then fails during the period T_R with average probability $\frac{1}{2}\lambda T_R$. For the third contribution the average unavailability $\frac{1}{2}\lambda T_R$ is used instead of the time dependent contribution, λt, $0 \leq t \leq T_R$, however since Q is in general much larger than λT_R, the error is insignificant.

3.5.2 Resulting Instantaneous and Average Unavailabilities

Figure A-5 illustrates the instantaneous unavailability behavior with the test and repair contributions q_1 and q_2 now included along with the between test contribution. The figure shows a sawtoothed plot with test and repair plateaus given by q_1 and q_2. Even though the test and repair periods τ and T_R are of short duration, the unavailability contributions q_1, q_2 can be important contributors to the peak and average unavailabilities attained by the component or by the system.

The average unavailability $\bar{q}$ can be computed to be the area of the time dependent, instantaneous unavailability curve divided by the total time interval, where the time interval is the interval of interest, such as one year. If the instantaneous unavailability has a cyclic behavior, then the average unavailability can be taken as the area over one periodic cycle divided by the cycle time. Considering Figure A-5 and taking T_2 to be the cycle time (the effect of the different first test interval T_1 is generally small), the average component unavailability $\bar{q}$ is thus approximately

$$\bar{q} = \frac{1}{2}\lambda T_2 + q_1\frac{\tau}{T_2} + q_2\frac{T_R}{T_2} \quad (18)$$

The first term on the right hand side of Equation (18) is the between tests contribution, the second term is the test contribution, and the third term is the repair contribution. (The small effect of the origin shift $(T_2-\tau)$ is ignored in the first term $\frac{1}{2}\lambda T_2$.) FRANTIC actually computes the average unavailability for a system from the time dependent unavailability plot. When the system is simply one component, the difference from Equation (18) will in general be insignificant.

In certain situations, the test and repair contributions can be dominant contributors to the average unavailability. For example, for no test override capability, $q_1 = 1$ and the average test contribution $q_1\tau/T_2$ thus becomes τ/T_2. If $\tau = 1$ hour and $T_2 = 720$ hours (30 days), this testing contribution is 1.4×10^{-3} which is relatively large and hence can be the principal contributor. The maximum instantaneous unavailability also occurs during testing since $q_1 = 1$ which implies that the component is unavailable were an accident to occur at this time.

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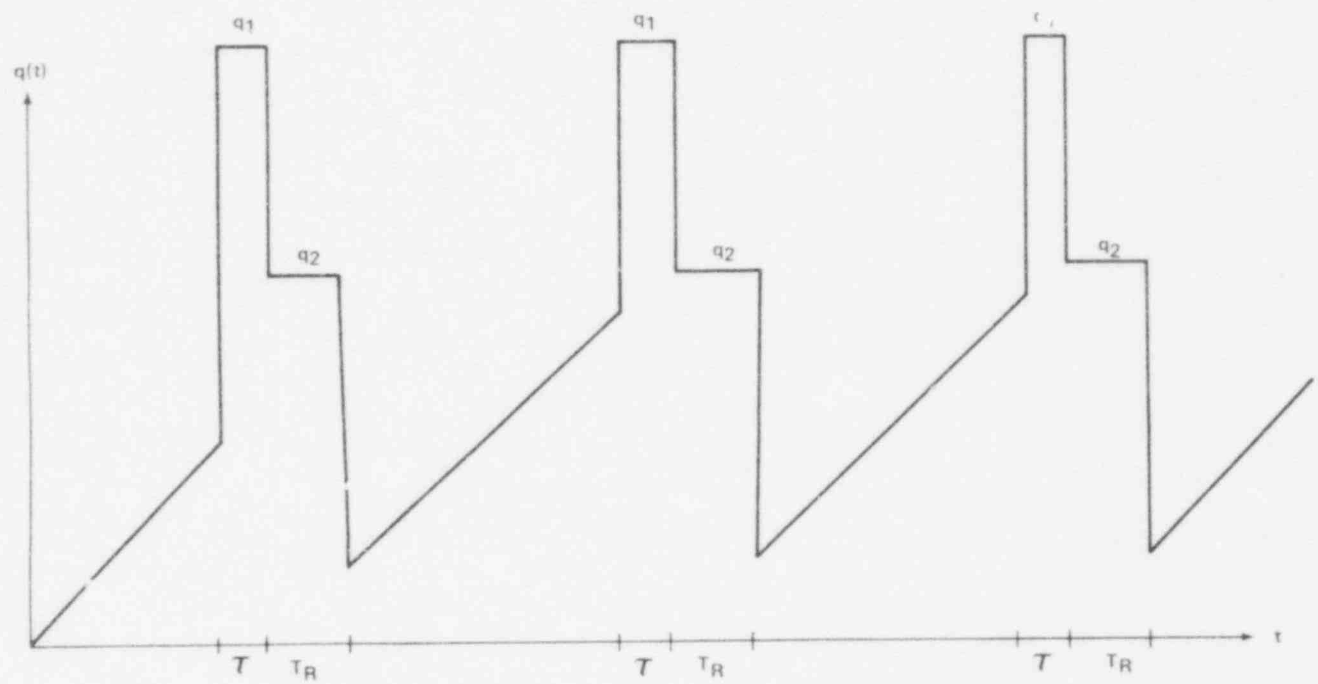
Figure A-5

The Instantaneous Unavailability Including Test and Repair Contributions (q_1, and q_2).



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Even with test overrides and with smaller test or repair periods, the unavailability contributions from testing or repair can still be important. For complex systems where the results are not as apparent as for a single component, the FRANTIC code will need to be run to obtain the various contributions. When testing and repair contributions are ignored then τ and T_R can be set to zero and the contributions q_1 and q_2 will not be computed. It must be recognized, however, that these situations represent perfect testing and repair, and the results must be so interpreted.

3.5.3 The Handling of Detection Inefficiencies

The previous equations for periodically tested components assume all failures are detectable by the tests. Detection inefficiencies can also be modeled in FRANTIC. Let p be the detection inefficiency, which is defined to be the fraction of failures which are not detectable by the test. When detection inefficiencies are modeled in FRANTIC ($p > 0$), then all the failure rates in the previous equations (Equations (10) - (15)) are changed in the code to $\lambda(1-p)$ which is the detectable failure rate. An undetected unavailability contribution q' is then separately added as given by

$$q' = \lambda pt \qquad (19)$$

This undetected unavailability is thus treated as a nonrepairable contribution and when this is added to Equations (10) - (15), the total component unavailability continually increases with time until a more efficient test is performed (such as at reactor shutdown). The detection inefficiency p can be varied in FRANTIC to determine the effects of testing efficiency; when p is set to zero, 100% detection is then effectively assumed.

4. SUMMARY OF EQUATIONS

The unavailability equations which have been previously given are summarized below for convenient reference.

(1) Constant unavailability components

$$q = q_d$$

where q_d is the constant, per demand unavailability

(2) Nonrepairable components

$$q(t) = \lambda t$$

where λ is the constant component failure rate.

(3) Monitored components

$$q = \lambda T_R$$

where

$$T_R = \text{average detection plus repair time}$$

(4) Periodically Tested Components

Between test contribution:

$$q(t) = \lambda(t-\tau)$$

Test contribution:

$$q_1 = p_f + (1 - p_f)q_o + (1-p_f)(1-q_o)Q$$

Repair contribution:

$$q_2 = p_f + (1 - p_f)Q + (1 - p_f)(1 - Q)\tfrac{1}{2} \lambda T_R$$

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where

t = the time from the preceding test

T_2 = test interval

τ = test period

T_R = repair period

p_f = probability of test-caused failure

$Q = \lambda(T_2 - \tau)$

For the first test interval T_1, the between test contribution is modified to $q(t) = \lambda t$, and Q for the first test is modified to λT_1. For periodic detection inefficiencies, λ in the above equations is modified to $\lambda(1 - p)$ and an undetected contribution q' is added where $q' = \lambda pt$.

Finally, human error and common mode contributions can be handled by using one of the above unavailability expressions (usually $q = q_d$).

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B. INPUT DESCRIPTION

1. INTRODUCTION

The FRANTIC code is set up to calculate the unavailability from a system unavailability equation or equations. A subroutine called SYSCOM is input by the user and gives the formula for the system unavailability in terms of the component unavailabilities. The formula is obtained from a block diagram, fault tree, event tree, etc. using standard Boolean techniques [3]. The SYSCOM subroutine may contain any number of system formulas to be evaluated in one FRANTIC run. Each formula has its own identifying index in SYSCOM.

In addition to the subroutine containing the system formulas, the user must supply failure rate and test data for a FRANTIC run. This data is broken up into cases, where each case defines the input information for a particular evaluation. The SYSCOM routine is described in Section B.5 and the data which comprise the cases are discussed in the sections below.

2. CASES

A given FRANTIC run consists of one or more cases. A case is described by the following data:

- A set of components which make up the system whose unavailability is to be studied.

- An index number designating the system or subsystem unavailability function to be calculated.

- Titles, print and plot options.

The data input scheme allows a simple method for running multiple cases whereby only that data which differs from the previous case need be entered. The program run terminates when no further cases are detected in the input stream.

3. DATA GROUPS

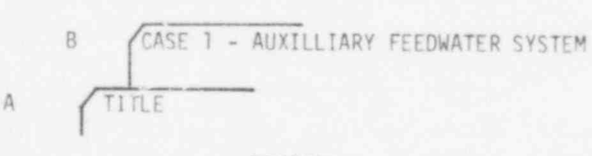
Cases are described by six sets of data cards which are called "data groups." Each data group consists of a keyword card which identifies the data group, and one or more additional cards. A complete program run can be initiated with three data groups; the other three are optional. The six data groups are described below.

3.1 Data Group 1: TITLE

This data group specifies the title for the case to be run. It consists of a keyword card containing the characters "TITL" in the first 4 columns (only the first four characters need be entered for this and all other keyword cards) followed by a card containing 80 characters of text to be printed as a header on the output report for the case. This data group is depicted in Figure B-1.

Figure B-1

Data Group 1 - Title



	Cols.	PROGRAM VARIABLE	FORMAT	DESCRIPTION
Card Type A	1-4	ANAME	A4	Keyword "TITL"
Card Type B	1-80	TITLE1	20A4	Title for output

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3.2 Data Group 2: COMPONENTS

This data group describes the components which make up the system to be evaluated. It is identified by a keyword card beginning with the characters "COMP." This card must be followed by a card beginning with the characters "NEW" or "UPDATE." "NEW" indicates that the components to be input are to become the effective component set for the case, replacing previously input components (if any). "UPDATE" indicates that only the non-blank component parameters are to be used in updating corresponding parameters for previously input components. Additional components may also be added to a previously existing set under the UPDATE option. After the "NEW" or "UPDATE" card, one card must be entered for each component. This card contains the component number, the component name, and 10 parameters describing the reliability data for the component. A number of the parameters will be left blank, depending on the type of component.

Under the "NEW" option, component numbers should be sequential, starting with one. The program will override any violation of this rule and print a warning. The requirement for these sequential numbers is really a check for the user under the "NEW" option.

Under the "UPDATE" option, the component numbers are used as keys to identify components to be updated and non-blank fields on the following component cards replace the old values for the corresponding parameters. A negative number must be used to zero out a parameter, effectively making a blank field. The only exception to this rule is the first test interval field T_1 for periodic components. If T_2 is altered in a change-case and T_1 is left blank, then T_1 is set equal to T_2 (instead of being left the same as in the previous case). Also if a -1 is input for T_1 in a change-case, T_1 will be set to the current value of T_2.

New components may be added under the "UPDATE" option by using sequential component numbers starting with one greater than the largest component number previously input. Deletion capability is not provided. Extra components can always be added since the system unavailability function need only use a subset of the input components. Thus it is valid to include components which are not used in some cases. (The TIME data group, given later, discusses the use of dummy components to increase the number of time points.)

The 10 parameters on the component cards are listed in the table below:

Component Parameters

Symbol	Fortran Variable Name	Description
λ	LAMDA	Failure rate per hour in multiples of 10^{-6}
T_2	TEST2	Periodic test interval in days
T_1	TEST1	First test interval in days if different from T_2
τ	TAU	Average test period in hours
T_R	REPAIR	Average repair period in hours
q_o	QOVR	Test override unavailability
p_f	PTCF	Probability of test-caused failure
p	INEFF	Detection inefficiency (probability of not detecting a failure)
λ_μ	ULAMDA	Undetected failure rate per hour in multiples of 10^{-6}
q_d	QRESID	Constant unavailability per demand

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If p is input as a non-zero value, the program will recompute λ as follows:

$$\lambda_1 = \lambda(1-p)$$

If p is inp . and λ_μ is left blank, the program will compute λ_μ as follows:

$$\lambda_\mu = \lambda p$$

The 10 parameters described above allow the user to specify most types of components under a variety of testing schemes:

Periodically tested components - the user must provide λ, T_2, and optionally, T_1, τ, T_R, q_o, p_f, p, λ_μ, and q_d

Monitored components - λ and T_R must be input; T_2 must be zero or left blank; T_1, q_o and p_f are ignored; and p, λ_μ, and q_d are optional. If τ is input it is added to T_R.

Nonrepairable components - λ, T_2, T_1, τ, and T_R must be zero or left blank; q_o p_f, p, and q_d are ignored; and λ_μ must be input. Alternatively, λ may be input instead of λ_μ. In this case, T_2 should be set to a value greater than the total time period of interest.

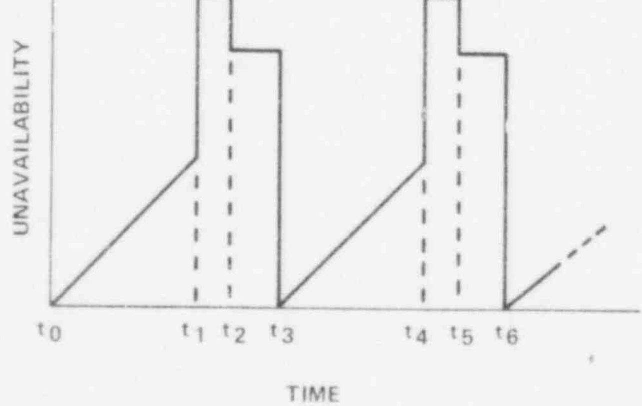
Constant unavailability - all parameters except q_d must be zero or left blank and a value for q_d be input.

The last card of the components data group contains "-1" in the component number field. This indicates the end of the data for the group. The maximum number of components is 100. The COMPONENTS data group is depicted in Figure B-2.

3.3 Data Group 3: TIME (Optional)

This data group specifies the time period over which component and system unavailabilities are to be computed. It consists of a keyword card beginning with the characters "TIME" followed by a single card containing the total time (in days) over which the time dependent, instantaneous unavailability is to be computed. If the data group (including the keyword card) is omitted, or if a zero is entered for the time period, the default value, 365 days, t s effect.

The number of time points generated by the code within the time period is a function of the test intervals, testing times, and repair times of the components. A pair of points is generated wherever a change in the slope of any component unavailability function occurs. For example, suppose a particular component has the following time dependent unavailability function:



TIME

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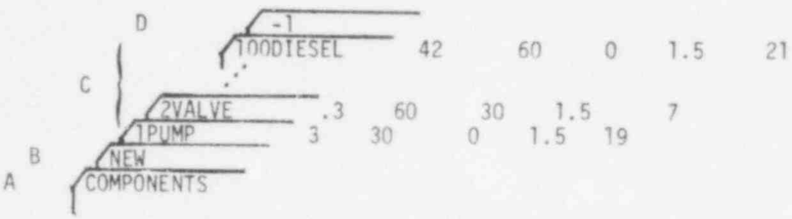
Figure B-2

Data Group 2 - COMPONENTS



	COLS	PROGRAM VARIABLE	FORMAT	DESCRIPTION
Card Type A	1-4	ANAME	A4	Keyword "COMP"
Card Type B	1-4	TYPE	A4	Option "NEW" or "UPDA"
Card Type C	1-5	INDX	I5	Component number
	6-13	NAME	A8	Component name
	14-19	LAMDA	F6.0	Failure rate in multiples of 10^{-6}
	20-25	TEST2	F6.0	Test interval in days
	26-31	TEST1	F6.0	Length of first test interval in days if different from TEST2
	32-37	TAU	F6.0	Average testing time in hours
	38-43	REPAIR	F6.0	Average repair time in hours
	44-49	QOVRD	F6.0	Unavailability of the override capability
	50-55	PTCF	F6.0	Probability of test-caused failure
	56-61	INEFF	F6.0	Detection inefficiency
	62-67	ULAMDA	F6.0	Rate of undetected failures in multiples of 10^{-6}
	68-73	QRESID	F6.0	Residual unavailability

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The program will generate time points at $t_0+\varepsilon$, $t_1-\varepsilon$, $t_1+\varepsilon$, $t_2-\varepsilon$, $t_2+\varepsilon$, $t_3-\varepsilon$, $t_3+\varepsilon$, ...t_k-e where e is a small number epsilon (10^{-4} hours) and t_k is the total time specified in the TIME data group (or the 365 day default value). Time points for all the other components are generated in a similar manner. All the points are then merged and duplicate points discarded. Component and system unavailabilities are computed at the resulting list of time points.

The time points generated in FRANTIC are based on all the components input in the COMPONENTS data group regardless of whether they are actually used in the system unavailability function. Thus, the user can control the spacing of the time points by adding one or more dummy components with short test intervals.

The spacing of the time points affects the accuracy of the computed average (or mean) system unavailability and the appearance of the instantaneous unavailability plots. The more non-linear the system unavailability, the more time points are required for extremely precise evaluations. A lack of sufficient points can cause some distortions in the plots and yield somewhat conservative estimates of the average system unavailability.

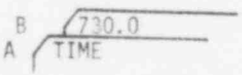
The conservatism occurs because the program computes the average system unavailability by numerical integration using the trapezoid rule (i.e., successive points are connected by straight lines and the area under the resulting function is computed). This method yields the correct area for the contributions to unavailability due to testing and repairs, but slightly overestimates any contribution due to failures (the between tests contribution). Rought upper bounds on the error incurred are given in the table below:

System Configuration	Maximum Error Factor
doubly redundant	1.5
triply redundant	2.0
quadruply redundant	2.5

As seen, the error factors are not generally large. If order of magnitude accuracies are required, then these errors will in general be insignificant. If desired, the user can always use more time points to check the errors made in the particular problem being analyzed. The TIME data group is depicted in Figure B-3.

Figure B-3

Data Group 3 - TIMES



	COLS	PROGRAM VARIABLE	FORMAT	DESCRIPTION
Card Type A	1-4	ANAME	A4	Keyword "TIME"
Card Type B	1-10	TEND	F10.0	Total time period in days (default = 365)

3.4 Data Group 4 - PRINT (optional)

This data group is used to request a table printout of the system unavailabilities computed by the program over one or more time intervals (within the input time period) and to specify the number of instantaneous unavailabilities to be separately ranked. The data group is identified by a keyword card beginning with the characters "PRIN." The keyword card must be followed by one card containing the number of time intervals desired and the number of maximum unavailabilities desired. The value input for the number of intervals may be -1, 0, 1, 2, 3, or 4.

If the value input is negative, all system unavailabilities computed are printed and no additional cards are necessary. If the value is zero, any print options previously

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specified are nullified and the default option (no print) is instituted. No additional cards are necessary. If the value is greater than zero, another card containing the end points of the intervals is read. In this case the program will print the system unavailability at all the computed time points that fall within the specified interval(s) including the end points. A maximum of four intervals may be specified.

The maximum unavailability output lists, in decreasing order, the n greatest instantaneous unavailabilities computed by the program. The number of unavailabilities printed (n) has a default value of 12 and may not exceed 100. If the PRINT data group (including the keyword card) is omitted, 12 peaks are printed, and no other system unavailability printout is produced. The PRINT data group is depicted in Figure B-4.

3.5 Data Group 5 - PLOT (Optional)

This data group is used to specify the time intervals used for plotting the system unavailability. It is identified by a keyword card beginning with the characters "PLOT." The keyword card must be followed by a card containing the number of intervals.

If the number of intervals is negative, the plot interval is set to the total time period over which points are computed and no additional cards are necessary. If this value is zero, any plot intervals previously input are nullified and the default plot interval is instituted. The default interval is given by:

$$\max_i (T_{1_i} + 2T_{2_i} + \tau_i + T_{R_i})$$

where T_{1i}, T_{2i}, τ_i, and T_{Ri} are the first test interval, second test interval, test time and repair time respectively for the ith component. The default interval is thus the three largest test cycles of any component, which is often sufficient for establishing the system behavior.

If the default plot interval exceeds the total time period, then the time period is used instead. If the number of intervals is greater than zero, another card containing the beginning and end points of each interval is read. A maximum of four intervals may be specified.

Note that unlike the PRINT data group which actually activates the system unavailability printout, the PLOT data group merely sets up the plot intervals which are to be used. Plots must be requested in the RUN data group in order for graphical output to be produced. If plots are requested in the RUN data group, one or more plots will be produced for each interval specified in the PLOT data group. If the PLOT data group (including the keyword card) is omitted, the plot period used is the default interval described above. Data group 5 is depicted in Figure B-5.

3.6 Data Group 6 - RUN

This data group initiates the system unavailability computations. The TITLE, COMPONENTS and optionally the TIME, PRINT and PLOT parameters must be set up before the RUN data group. The RUN data group is identified by a keyword card beginning with the characters "RUN."

The RUN keyword card must be followed by one or more run data cards, where each card has the following parameters.

(1) system number - number code identifying the system unavailability function to be used (see Section B.5, DEFINITION OF SYSTEM UNAVAILABILITY FUNCTIONS).

(2) unavailability option - four letter code selecting the type of unavailability to be computed where

> "FAIL" means compute the instantaneous unavailability based on contributions from component failures only (the between tests contribution).
>
> "TOTL" means compute the instantaneous unavailability based on contributions from failures, testing and repairs.
>
> When the unavailability option is left blank, the default value is "TOTL."

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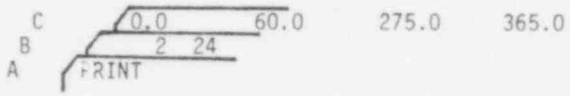
Figure B-4

Data Group 4 - PRINT



	COLS	PROGRAM VARIABLE	FORMAT	DESCRIPTION
Card Type A	1-4	ANAME	A4	Keyword = "PRIN"
Card Type B	1-5	NPRT	I5	Number of time intervals for printing system unavailabilities (-1, 0, or 1-4)
	6-10	NPK	I5	Number of peaks to be printed
Card Type C (use only when number of intervals is >0)	1-10	STPRT(1)	F10.0	Start of first time interval in days
	11-20	FINPRT(1)	F10.0	End of first time interval in days
	21-30	STPRT(2)	F10.0	Start of 2nd time interval in days
	31-40	FINPRT(2)	F10.0	End of 2nd time interval in days
	41-50	STPRT(3)	F10.0	Start of 3rd time interval in days
	51-60	FINPRT(3)	F10.0	End of 3rd time interval in days
	61-70	STPRT(4)	F10.0	Start of 4th time interval in days
	71-80	FINPRT(4)	F10.0	End of 4th time interval in days

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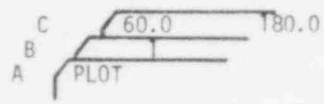
Figure B-5

Data Group 5 - PLOT



	COLS	PROGRAM VARIABLE	FORMAT	DESCRIPTION
Card Type A	1-4	ANAME	A4	Keyword = "PLOT"
Card Type B	1-5	NPLT	I5	Number of time intervals for plotting system unavailabilities (-1, 0, or 1-4)
Card Type C (use only when number of intervals is >0)	1-10	STPLT(1)	F10.0	Start of first time interval in days
	11-20	FINPLT(1)	F10.0	End of first time interval in days
	21-30	STPLT(2)	F10.0	Start of 2nd time interval in days
	31-40	FINFLT(2)	F10.0	End of 2nd time interval in days
	41-50	STPLT(3)	F10.0	Start of 3rd time interval in days
	51-60	FINPLT(3)	F10.0	End of 3rd time interval in days
	61-70	STPLT(4)	F10.0	Start of 4th time interval in days
	71-80	FINPLT(4)	F10.0	End of 4th time interval in days

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(3) x-scale - four letter code specifying the scaling of the points along the x or time axis where

"NONE" means no plots are produced

"LIN" means a linear scale is used for the time points

"MAG" means that the time points are spaced at equal intervals regardless of the actual elapsed time between the points. This produces a plot in which the test and repair contributions are magnified so that the structure of the system unavailability function is easier to see. The indices of the time points are plotted along the x-axis.

"BOTH" means both "LIN" and "MAG" scales are used. Two plots are produced for each y-scale selected.

If x-scale is left blank, the default value is "LIN' when the unavailability option is "FAIL", "BOTH" when the unavailability option is "TOTL."

(4) y-scale - four letter code specifying the scaling of the points along the y or system unavailability axis where

"NONE" means no plots are produced (may be omitted if x-scale = "NONE")

"LIN" means a linear scale is used for the system unavailabilities

"LOG" means a log scale is used for the system unavailabilities

"BOTH" means both "LIN" and "LOG" scales are used. Two plots are produced for each x-scale selected (e.g., if x-scale = "BOTH" and y-scale = "BOTH," four plots are produced for each time interval specified in the "PLOT" data group).

If y-scale is left blank, the default value is "LIN" when the unavailability option is "FAIL," "LOG" when the unavailability option is "TOTL."

(5) plot cutoff option - power of 10 to be used as a lower bound on system unavailability for plotting (e.g., -7 = 10^{-7}). The default is no cutoff.

(6) plot title - 56 character text to appear as a plot subheading in addition to the title for the case.

A negative system number indicates the end of the RUN data group. The RUN data group is depicted in Figure B-6.

4. CHANGE CASES

All data groups (except RUN) remain in effect until they are changed. To run change cases, simply modify or add the desired parameters using the appropriate data groups and follow these modifications by another RUN data group.

5. DEFINITION OF SYSTEM UNAVAILABILITY FUNCTIONS - SUBROUTINE SYSCOM

This section describes how to input the system unavailability function(s) for a FRANTIC run. The input is in the form of a FORTRAN subroutine which has the following format:

```
      SUBROUTINE SYSCOM(QC, QS, NSYS)
      DOUBLE PRECISION QC(100)

      GO TO (1, 2, ..., i), NSYS
    1 QS = f1 (QC)
      RETURN
    2 QS = f2 (QC)
      RETURN
        .
        .
        .
    i QS = fi (QC)
      RETURN
      END
```

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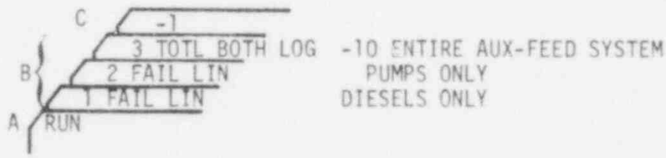
Figure B-6

Data Group 6 - RUN



	COLS	PROGRAM VARIABLE	FORMAT	DESCRIPTION
Card Type A	1-4	ANAME	A4	Keyword "RUN"
Card Type B	1-3	NSYS	I3	System unavailability function number
	5-8	QOPT	A4	Unavailability option
	10-13	XOPT	A4	X-scale option
	15-18	YOPT	A4	Y-scale option
	20-23	ICUTOP	I4	Cutoff option
	25-80	TITLE2	14A4	Plot title
Card Type C	1-4	NSYS	I3	End of run cards indicator (-1)

where

QS is the value of the system unavailability returned by the subroutine

QC is a double precision array of the component unavailabilities at a particular time point. These values are computed and passed to the SYSCOM subroutine by the FRANTIC program. The order of the components is based on the component numbers supplied by the user in the COMPONENTS data group.

NSYS is the system unavailability function number input on one of the RUN data cards. It tells the subroutine which system unavailability function to use. If three functions are defined by the subroutine then NSYS would be an integer between 1 and 3

1, 2, ..., i are statement numbers at which i different unavailability functions are defined.[3] The definition of the functions may consist of one or more lines of FORTRAN code in which QS is defined as a function of one or more of the components in the array QC. It is not necessary to use all the values in the array QC since some of them may represent dummy components or components defined but not needed for every case

The placement of the SYSCOM subroutine in the input stream is described in the job control language sections.

6. JOB CONTROL - GENERAL REQUIREMENTS

This section gives a general description of the job steps needed to execute FRANTIC on any computer system assuming that the standard Calcomp routines PLOT, SYMBOL, NUMBER, SCALE, AXIS, and LINE, GRID, and LOGRID are available in object or load module form. The job steps are:

Step 1: (only once) Compile the FRANTIC source code to create an object or load module

Step 2: Compile the SYSCOM subroutine defining the system unavailability function(s) for the FRANTIC run (see B.5. DESCRIPTION OF SYSTEM UNAVAILABILITY FUNCTIONS), producing an object module.

Step 3: Link together the FRANTIC module from step 1, the SYSCOM module from step 2, and the Calcomp module.

Step 4: Execute the module resulting from step 3, using as input the cards described in the DATA GROUPS section.

7. JOB CONTROL LANGUAGE TO RUN AT NIH

Two versions of FRANTIC are set up to run at the National Institutes of Health computer center. One produces printer plots and the other produces Calcomp plots. The turn-around time for Calcomp plots is usually 1 to 2 working days (Monday through Friday only). Printer plots are returned with the regular output. The JCL required for the two types of runs is described in the following sections. The SYSCOM subroutine and DATA GROUP input are identical for the two runs.

[3]These functions are standard reliability equations obtained from block diagrams, fault trees, etc. (See references 2 and 3 for basic dscussions).

7.1 JCL for Calcomp Plots

To produce Calcomp plots submit a WYLBUR file with the following format:

```
//jobname JOB (aaaa,box,P),name
//STEP1 EXEC FORGCOMP
//COMP.SYSIN DD *
      SUBROUTINE SYSCOM(QC,QS,NSYS)
C
      DOUBLE PRECISION QC(1)
C
        enter body of SYSCOM subroutine here
C
      END
/*
//STEP2 EXEC CALLKGO,LIBNAME='HDCCVMB.FRANTIC.CALCOMP',LIBDISK=PDS006,
//  CORE=150K,PLTNAME=plotname
//LOAD.SYSLIN DD
//            DD *
   INCLUDE SYSLIB(MAIN)
   ENTRY MAIN
/*
//GO.FT05F001 DD *
/*UNN


        enter DATA GROUP input here


/*
```

where the fields in lower case letters must be supplied as follows:

jobname - the name of the job, eight characters or less beginning with the user's initials

aaaa - the user's account number

box - the user's box number

name - the user's last name

plotname- the name of the plot, eight characters or less beginning with the user's initials.

7.2 JCL for Printer Plots

To produce printer plots or to run a job without plots, submit a WYLBUR file with format:

```
//jobname JOB (aaaa,box,A),name
//STEP1 EXEC FORGCOMP
//COMP.SYSIN DD *
      SUBROUTINE SYSCOM(QC,QS,NSYS)
C
      DOUBLE PRECISION QC(1)
C
        enter body of SYSCOM subroutine here
C
      END
/*
//STEP2 EXEC IPPDLKGO,LIBNAME='HDCCVMB.FRANTIC.PRTPLOT',LIBDISK=PDS006,
//  CORE=150K
//LOAD.SYSLIN DD
//            DD *
   INCLUDE SYSLIB(MAIN)
   ENTRY MAIN
/*
//GO.FT05F001 DD *
/*UNN


        enter DATA GROUP input here


/*
//STEP3 EXEC IPPDPRT
```

where the fields in lower case letters must be supplied as follows:

jobname - the name of the job, eight characters or less beginning with the user's initials

aaaa - the user's account number

box - the user's box number

name - the user's last name

8. <u>LISTING OF SAMPLE INPUT DECK</u>

```
//VMBFRNTC JOB (WDCC,349,8),GOLDBERG
//STEP1 EXEC FORGCOMP
//COMP.SYSIN DD *
      SUBROUTINE SYSCOM(QC,QS,NSYS)
C
      DOUBLE PRECISION QC(1)
C
C*** SYSCOM SUBROUTINE FOR A SINGLE COMPONENT UNAVAILABILITY
      QS=QC(1)
      RETURN
C
      END
/*
//STEP2 EXEC CALLKGO,LIBNAME='WDCCVMB.FRANTIC.CALCOMP',LIBDISK=PDS006,
//  CORE=150K,PLTNAME=VMBSAMP
//LOAD.SYSLIN DD
//            DD *
   INCLUDE SYSLIB(MAIN)
   ENTRY MAIN
/*
//GO.FT05F001 DD *
/*UNN
TITLE
SINGLE COMPONENT (LAMBDA=3X10**-6, TEST INT=30 DAYS, TAU=1.5 HRS, REPAIR=19 HRS)
COMPONENTS
NEW
    1PUMP          3    30          1.5    19   .05
    2DUMMY         0    10
   -1
PRINT
    1    5
0.0         120.0
RUN
  1 FAIL                  UNAVAILABILITY DUE TO FAILURES ONLY
  1 TOTL BOTH BOTH    -7 UNAVAILABILITY DUE TO FAILURES, TESTING, AND REPAIRS
 -1
/*
```

The output produced by running the above sample problem is described in Section C.

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C. OUTPUT DESCRIPTION

This section discusses the output produced by program FRANTIC.

1. PRINTED OUTPUT

The FRANTIC program produces four output sections which are briefly described below. All output reports reproduced in this section may be generated by running the sample input problem from Section B.8.

1.1 Output Section 1 - Input Component Parameters

This output is a table containing the 10 parameters for each component input in the COMPONENTS data group. The table is printed each time a COMPONENTS data group is input. Under the NEW option, all components are printed. Under the UPDATE option, only the updated components are printed. This output section is depicted in Figure C-1. Note that the second component in Figure C-1 is a dummy component which has been included to increase the number of time points generated by the program.

1.2 Output Section 2 - Component Mean Unavailabilities

This output is a table in which the average unavailability of each component is listed and broken down percentage-wise into five contributions. These five contributions are the unavailability due to failures (the between tests contribution), the testing contribution, the repair contribution, the undetected failure contribution, and the constant per demand contribution (where applicable). The table is printed every time a COMPONENTS data group is read in. All components are listed. Output Section 2 is depicted in Figure C-2.

1.3 Output Section 3 - Time Point Data

This output lists the time points generated by the program. The time points are printed whenever a new set of time points is recomputed. This occurs whenever a TIMES data group is input, time-related component parameters are changed, or new components are input. The time point numbers or indices correspond to the point numbers on plots produced with x-scale = "MAG" (see GRAPHIC OUTPUT). Note that if t_i is the i^{th} time point, the program actually computes the component and system unavailabilities at the 2 points $t_i - \varepsilon$ and $t_i + \varepsilon$ where ε is a small number epsilon. Output Section 3 is depicted in Figure C-3.

1.4 Output Section 4 - System Unavailability Data

This output is printed every time a RUN data group is input. The average (mean) system unavailability, averaged over the total time period, and the requested options are printed for each run data card in the input stream. The average system unavailability is broken down into the contributions due to failure, testing, and repairs according to the following rules:

(1) If at least one component is under test then the instantaneous system unavailability is counted toward the test contribution.

(2) If no components are under test and at least one component is down for repair, then the instantaneous system unavailability is counted towards the repair contribution.

(3) If no components are under test or repair, the instantaneous system unavailability is counted towards the failure contribution (i.e., between test contribution).

The contributions to the average unavailability are computed by integrating over the appropriate instantaneous unavailabilites (1, 2, or 3 above) and dividing by the total time period. In addition to the contribution breakdowns, the n highest instantaneous unavailabilities are printed under the heading "Peak System Unavailabilities" where the default value for n is 12. Other values of n may be specified (see Data Group 5 - PRINT). In the output shown in Figure C-4 the five highest unavailabilities are printed.

If requested in the PRINT data group, average unavailability contributions for each time increment may be printed. These average incremental contributions can be obtained for one or more time increments. In Figure C-4, incremental unavailabilities are obtained for the time period of zero to 120.0 days. The value under the heading "UNAVAIL INCREMENT" for

Figure C-1

Input Component Parameters

SINGLE COMPONENT (LAMBDA=3X10**-6, TEST INT=30 DAYS, TAU=1.5 HRS, REPAIR=19 HRS)

***** INPUT COMPONENT PARAMETERS *****

COMP NUMB	COMP NAME	FAILURE RATE (PER HR)	TEST INTERVAL (DAYS)	FIRST INTERVAL (DAYS)	TIME FOR TESTING (HRS)	TIME FOR REPAIRS (HRS)	OVERRIDE UNAVAIL	PROB OF TEST-CAUSED FAILURE	TEST INEFF	UNDETECT FAIL RATE (PER HR)	RESIDUAL UNAVAIL
1	PUMP	3.00E-06	3.00E+01	3.00E+01	1.50E+00	1.90E+01	5.00E-02	0.0	0.0	0.0	0.0
2	DUMMY	0.0	1.00E+01	1.00E+01	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure C-2

Component Mean Unavailabilities

SINGLE COMPONENT (LAMBDA=3X10**-6, TEST I... 30 DAYS, TAU=1.5 HRS, REPAI. 19 HRS)

***** COMPONENT MEAN UNAVAILABILITIES ****

COMP NUMB	COMP NAME	TOTAL UNAVAIL	UNAVAIL DUE TO FAILURES	% OF TOTAL	UNAVAIL DUE TO TESTING	% OF TOTAL	UNAVAIL DUE TO REPAIRS	% OF TOTAL	UNAVAIL DUE TO UNDET FAIL.	% OF TOTAL	RESIDUAL UNAVAIL	% OF TOTAL
1	PUMP	1.239E-03	1.073E-03	86.63	1.082E-04	8.73	5.751E-05	4.64	0.0	0.0	0.0	0.0
2	DUMMY	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure C-3

Time Point Data

SINGLE COMPONENT (LAMBDA=3X10**-6, TEST INT=30 DAYS, TAU=1.5 HRS, REPAIR=19 HRS)

***** TIME POINT DATA *****

THE NUMBER OF POINTS GENERATED = 62
TOTAL TIME PERIOD IN HOURS (DEFAULT=1 YR) = 8760.000

THE TIME POINTS (IN HOURS) ARE PRINTED BELOW:

1 =	0.0	2 =	2.4000E+02	3 =	4.8000E+02	4 =	7.2000E+02	5 =	7.2150E+02
6 =	7.4050E+02	7 =	9.6000E+02	8 =	1.2000E+03	9 =	1.4400E+03	10 =	1.4415E+03
11 =	1.4605E+03	12 =	1.6800E+03	13 =	1.9200E+03	14 =	2.1600E+03	15 =	2.1615E+03
16 =	2.1805E+03	17 =	2.4000E+03	18 =	2.6400E+03	19 =	2.8800E+03	20 =	2.8815E+03
21 =	2.9005E+03	22 =	3.1200E+03	23 =	3.3600E+03	24 =	3.6000E+03	25 =	3.6015E+03
26 =	3.6205E+03	27 =	3.8400E+03	28 =	4.0800E+03	29 =	4.3200E+03	30 =	4.3215E+03
31 =	4.3405E+03	32 =	4.5600E+03	33 =	4.8000E+03	34 =	5.0400E+03	35 =	5.0415E+03
36 =	[illegible] 0605E+03	37 =	5.2800E+03	38 =	5.5200E+03	39 =	5.7600E+03	40 =	5.7615E+03
41 =	[illegible].7805E+03	42 =	6.0000E+03	43 =	6.2400E+03	44 =	6.4800E+03	45 =	6.4815E+03
46 =	6.5005E+03	47 =	6.7200E+03	48 =	6.9600E+03	49 =	7.2000E+03	50 =	7.2015E+03
51 =	7.2205E+03	[illegible] =	7.4400E+03	53 =	7.6800E+03	54 =	7.9200E+03	55 =	7.9215E+03
56 =	7.9405E+03	57 =	8.1600E+03	58 =	8.4000E+03	59 =	8.6400E+03	60 =	8.6415E+03
61 =	8.6605E+03	62 =	8.7600E+03						

Figure C-4

System Unavailability Data

SINGLE COMPONENT (LAMBDA=3X10**-6, TEST INT=30 DAYS, TAU=1.5 HRS, REPAIR=19 HRS)

***** SYSTEM UNAVAILABILITY DATA *****

RUN OPTIONS:

SYSTEM DESCRIPTION	EQUATION NUMBER	UNAVAIL. OPTION	PLOT OPTIONS X	PLOT OPTIONS Y	CUTOFF OPTION
UNAVAILABILITY DUE TO FAILURES, TESTING, AND REPAIRS		TOTL	BOTH	BOTH	-7

SYSTEM MEAN UNAVAILABILITIES BETWEEN ZERO AND 365.00 DAYS:

TOTAL MEAN UNAVAIL	UNAVAIL DUE TO FAILURES	% OF TOTAL	UNAVAIL DUE TO TESTING	% OF TOTAL	UNAVAIL DUE TO REPAIRS	% OF TOTAL
1.227E-03	1.063E-03	86.65	1.069E-04	8.72	5.685E-05	4.63

PEAK SYSTEM UNAVAILABILITIES:

POINT NUMBER	TIME (DAYS)	TIME (HOURS)	SYSTEM UNAVAIL
5	3.0063E+01	7.2150E+02	5.2052E-02
10	6.0063E+01	1.4415E+03	5.2048E-02
15	9.0063E+01	2.1615E+03	5.2048E-02
20	1.2006E+02	2.8815E+03	5.2048E-02
25	1.5006E+02	3.6015E+03	5.2048E-02

SYSTEM UNAVAILABILITIES BETWEEN 0.0 AND 120.00 DAYS:

POINT NUMBER	TIME (DAYS)	TIME (HOURS)	UNAVAIL AT T-EPSILON	UNAVAIL AT T+EPSILON	UNAVAIL. INCREMENT	PERCENT OF TOTAL	AREA TYPE
1	0.0	0.0		3.0000E-10			
2	1.0000E+01	2.4000E+02	7.2000E-04	7.2000E-04	3.0000E-05	2.4987	
3	2.0000E+01	4.8000E+02	1.4400E-03	1.4400E-03	9.0000E-05	7.4560	
4	3.0000E+01	7.2000E+02	2.1600E-03	5.2052E-02	1.5000E-04	12.4933	
5	3.0063E+01	7.2150E+02	5.2052E-02	2.1884E-03	2.7110E-05	2.2580	T
6	3.0854E+01	7.4050E+02	2.1884E-03	5.7000E-05	1.4438E-05	1.2025	R
7	4.0000E+01	[illegible].6000E+02	7.1550E-04	7.1550E-04	2.9438E-05	2.4519	
8	5.0000E+01	[illegible].2000E+03	1.4355E-03	1.4355E-03	8.9625E-05	7.4647	
9	6.0000E+01	1.4400E+03	2.1555E-03	5.2048E-02	1.4963E-04	12.4621	
10	6.0063E+01	1.4415E+03	5.2048E-02	2.1839E-03	2.7108E-05	2.2578	T
11	6.0854E+01	1.4605E+03	2.1839E-03	5.7000E-05	1.4408E-05	1.2000	R
12	7.0000E+01	1.6800E+03	7.1550E-04	7.1550E-04	2.9438E-05	2.4519	
13	8.0000E+01	1.9200E+03	1.4355E-03	1.4355E-03	8.9625E-05	7.4647	
14	9.0000E+01	2.1600E+03	2.1555E-03	5.2048E-02	1.4963E-04	12.4621	
15	9.0063E+01	2.1615E+03	5.2048E-02	2.1839E-03	2.7108E-05	2.2578	T
16	9.0854E+01	2.1805E+03	2.1839E-03	5.7000E-05	1.4408E-05	1.2000	R
17	1.0000E+02	2.4000E+03	7.1550E-04	7.1550E-04	2.[illegible]438E-05	2.4519	
18	1.1000E+02	2.6400E+03	1.4355E-03	1.4355E-03	8.9625E-05	7.4647	
19	1.2000E+02	2.8800E+03	2.1555E-03	5.2048E-02	1.4963E-04	12.4621	

SYSTEM MEAN UNAVAILABILITIES BETWEEN 0.0 AND 120.00 DAYS:

TOTAL MEAN UNAVAIL	UNAVAIL DUE TO FAILURES	% OF TOTAL	UNAVAIL DUE TO TESTING	% OF TOTAL	UNAVAIL DUE TO REPAIRS	% OF TOTAL
1.201E-03	1.076E-03	89.62	8.133E-05	6.77	4.325E-05	3.60

POOR ORIGINAL

763 034

time period i is the area under the system unavailability function between points i-1 and i divided by the length of the total time period (120 days in this case). The percentage contribution to the average unavailability over the total period is given in the next column and the last column is the contribution type (T for testing, R for repairs, blank for failures) computed according to rules 1-3 described above.

1.5 Output Termination Message

If the run terminates normally, the message "END OF FRANTIC RUN" will appear after the output for the last RUN data group.

2. GRAPHIC OUTPUT

The FRANTIC program is capable of producing four different kinds of plots. The plots generated depend on the options specified on the run data cards (see Data Group 6 - RUN). The four types of plots are described below.

2.1 LIN-LIN Plot

Both the time (x) scale and unavailability (y) scale are linear. This type of plot is shown in Figures C-5 and C-6.

2.2 MAG-LIN Plot

The time (x) scale is magnified and the unavailability (y) scale is linear. The term "magnified" means that all points along the time axis are plotted at equal intervals; the points actually plotted are the time point indices. Since short intervals are magnified, the full structure of the instantaneous unavailability function is more readily visible. This type of plot is shown in Figure C-7.

2.3 LIN-LOG Plot

The time (x) scale is linear and the unavailability (y) scale is logarithmic (base 10). The log scale is useful when availabilities vary by orders of magnitude. This will often occur when the "TOTL" unavailability option is used (see Data Group 6 -RUN). A LIN-LOG plot is shown in Figure C-8.

2.4 MAG-LOG Plot

The time (x) scale is magnified and the unavailability (y) scale is logarithmic. This plot combines the advantages of the MAG and LOG options as described above. A MAG-LOG plot is shown in Figure C-9.

2.5 Cutoff Option

The cutoff option (see Data Group 6 - RUN) may be used to improve the appearance of the plots. In Figures C-6, C-7, C-8, and C-9, a cutoff value of 10^{-7} was used for the unavailability. This means that values of the system unavailability below 10^{-7} are not plotted, thereby decreasing the range shown on the y-axis. For readable LOG plots, the number of orders of magnitude plotted on the y-axis is best kept to ten or less.

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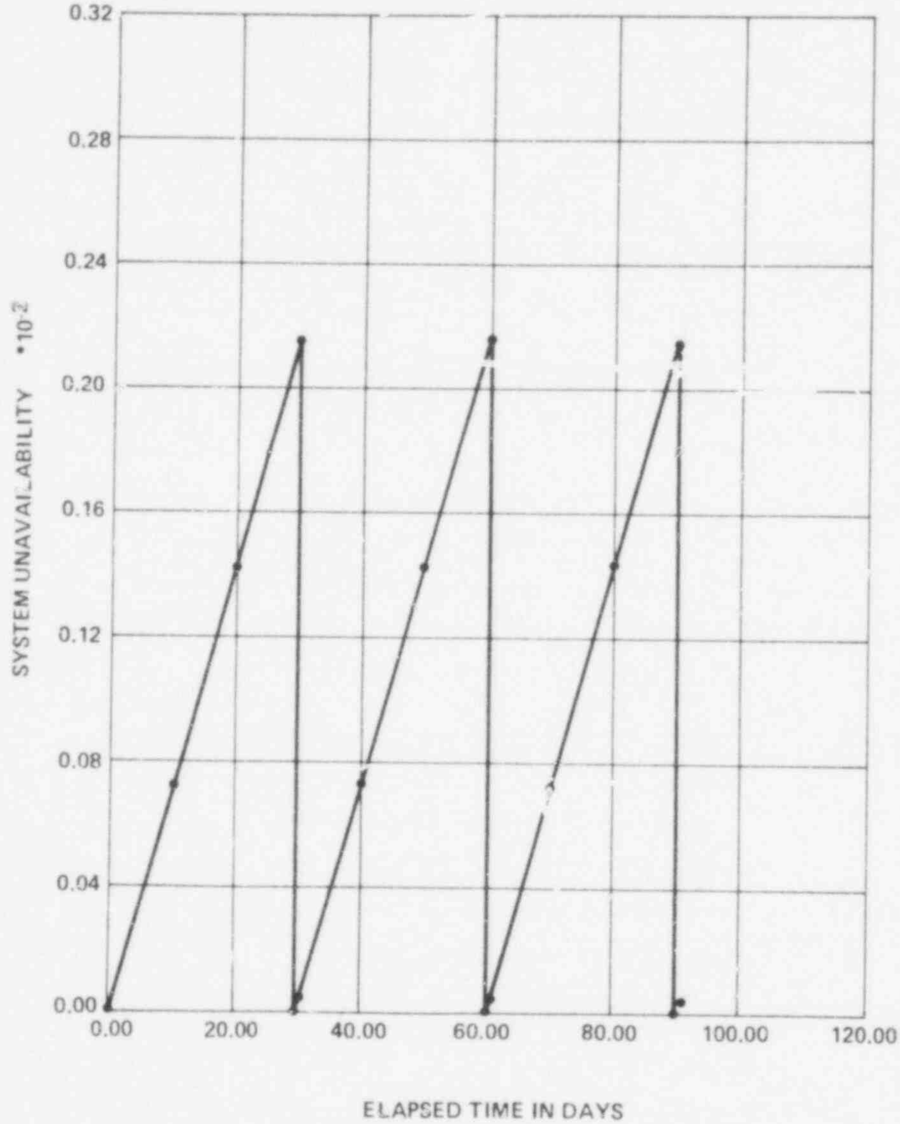
Figure C-5

LIN-LIN Plot, Unavailability Option - "FAIL"



763 036

Figure C-6

LIN-LIN Plot, Unavailability Option - "TOTL"

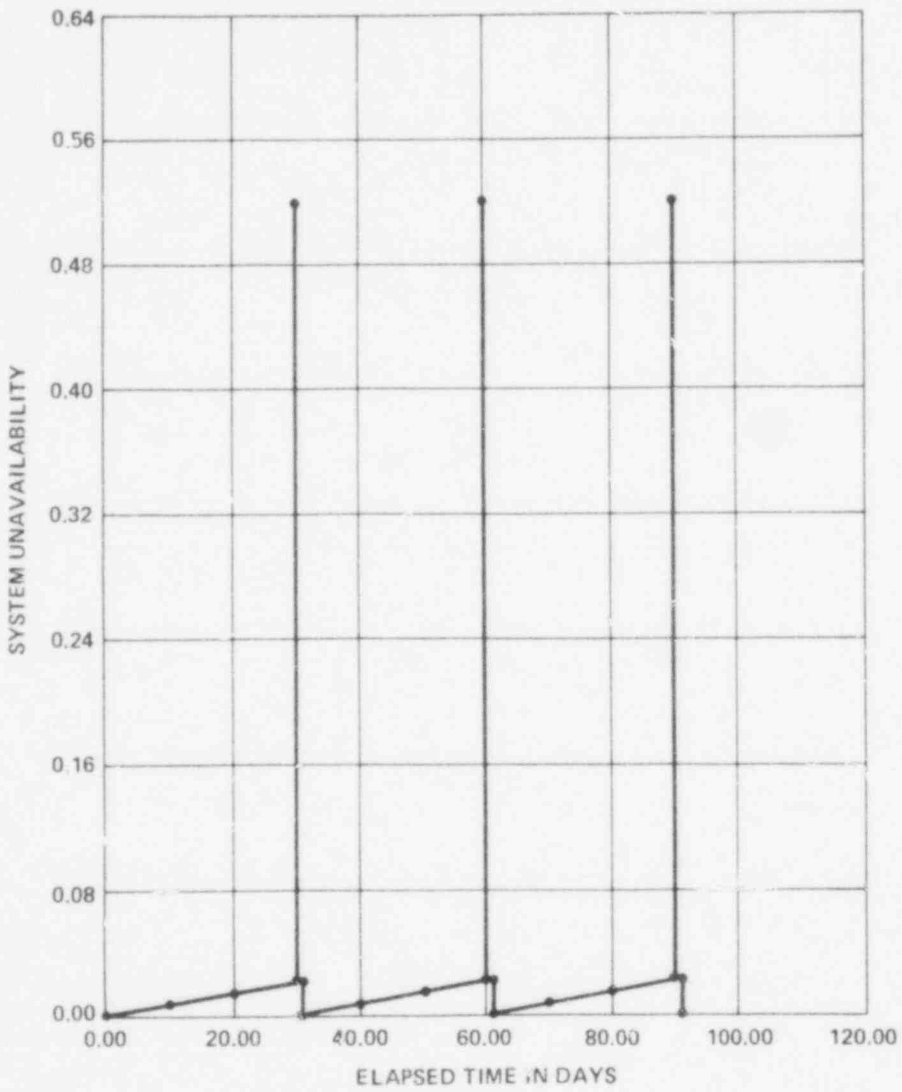
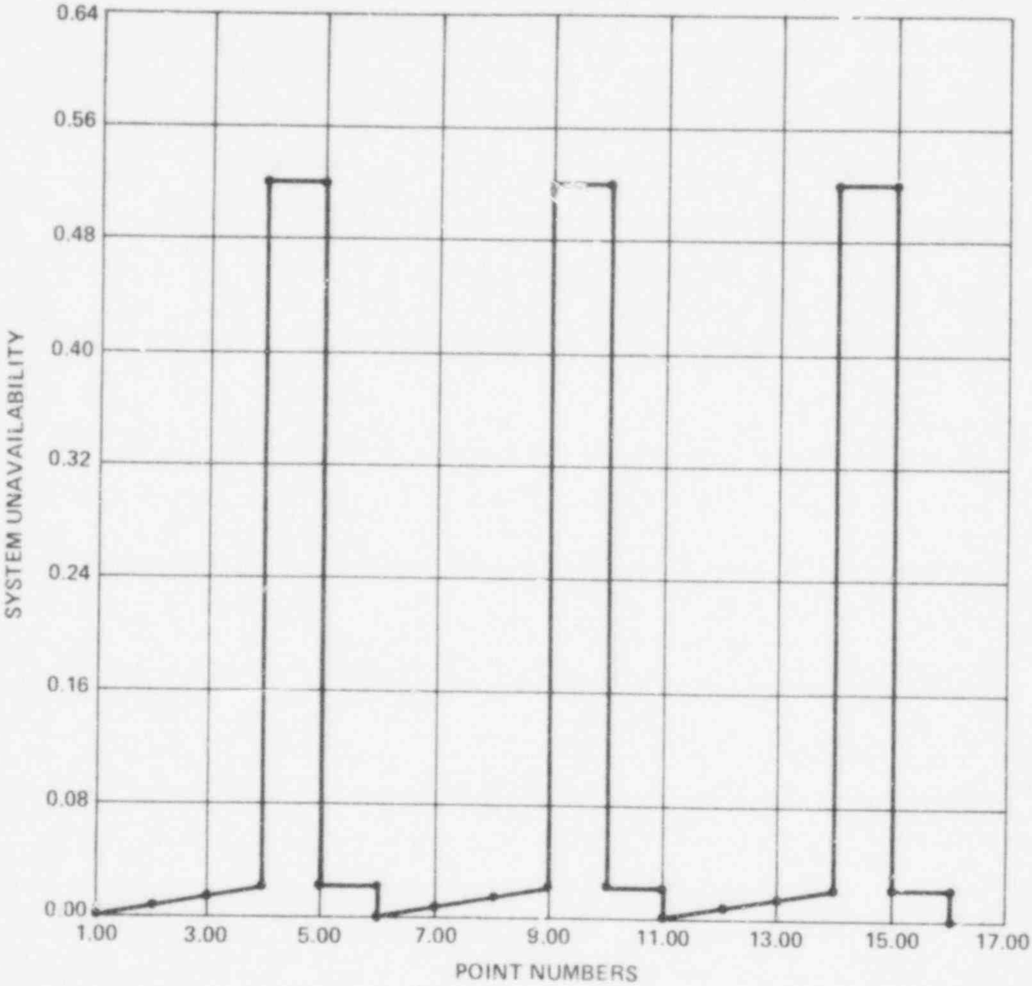


Figure C-7

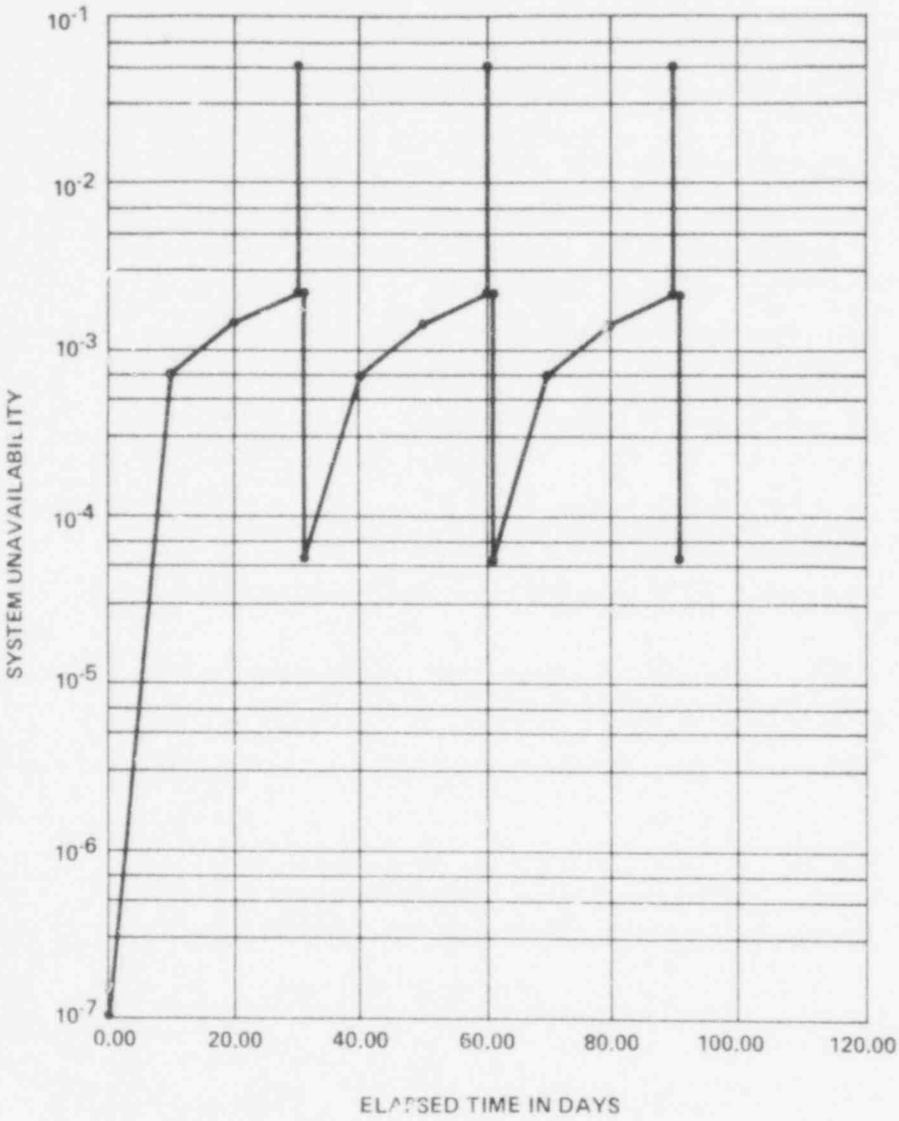
MAG-LIN Plot, Unavailability Option - "TOT!"



763 038

Figure C-8

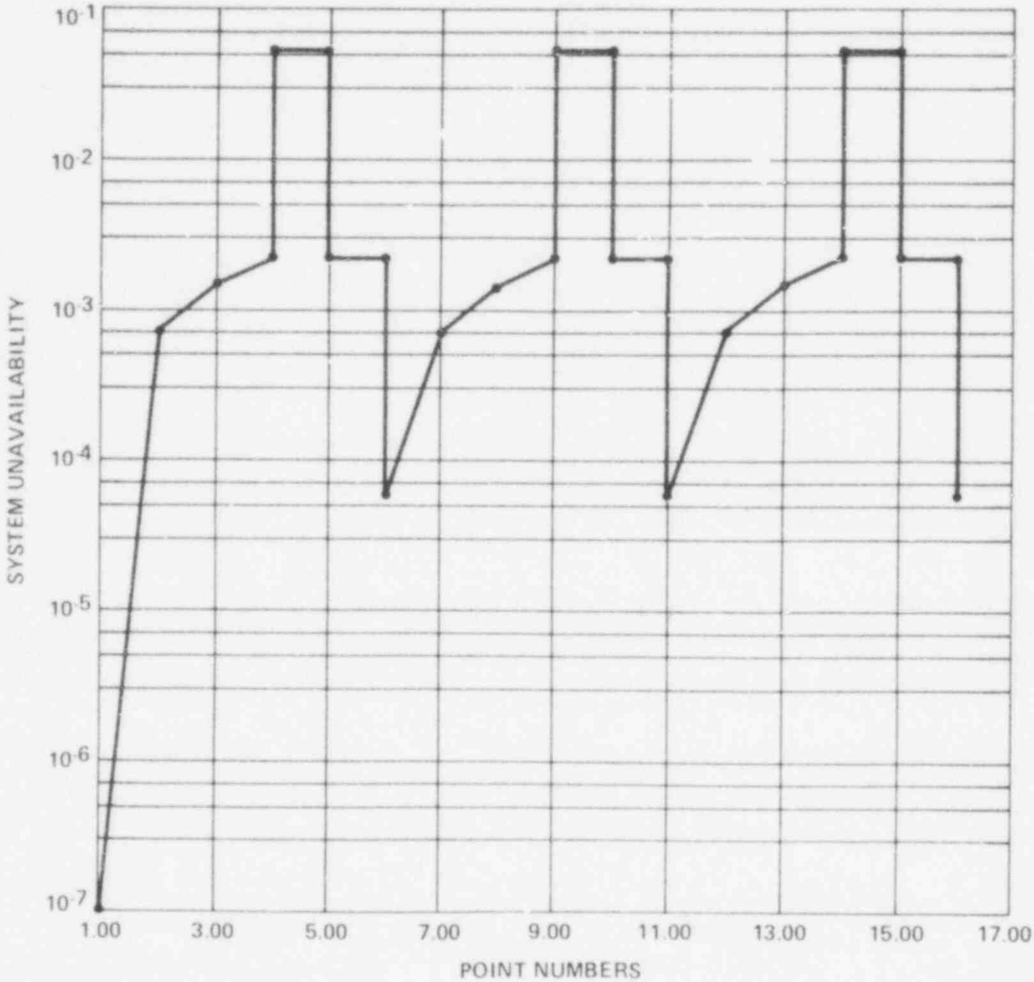
LIN-LOG Plot, Unavailability Option - "TOTL"



763 039

Figure C-9

MAG-LOG Plot, Unavailability Option - "TOTL"



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D. APPLICATIONS

Four example problems are discussed here to illustrate the range of applications of the FRANTIC code. The discussion format consists of the purpose of the problem, the input required, the output produced, and comments on the results.

1. EXAMPLE 1: TEST INEFFICIENCY SENSITIVITY STUDY

Purpose: To study the instantaneous and average unavailability resulting from different test inefficiencies p (the test inefficiency is defined in Section A, 3.5.3).

Input The system consists of a pump and two manual valves in series as shown in Figure D-1. The valves are closed for the pump test and the pump and valves are thus treated as being tested at the same time. During the test, the pump and valves are unavailable for operation. The same test inefficiency p is applied to the pump and the valves. (Because of the differences in failure rates, the unavailability contribution from the valves is small compared to the contribution from the pump and hence the valve modeling is not really significant here.) Figure D-2 shows the basic component input (p=0) and the change-case input for p = 0.1 and p = 0.5. A fictitious component is added to the input to increase the number of time points for the FRANTIC analysis. Figure D-3 shows the SYSCOM subroutine describing the system logic.

Output: Figures D-4 through D-6 show the FRANTIC system unavailability plots (MAG plots) for the different values of p. In the figures the two smaller steps following the large testing spike are the repair contributions which result from the different valve and pump repair times given as input data. The average system unavailability, computed over a one year interval, is also given with the respective figure.[4] Figure D-7 gives the times corresponding to the point numbers in the plots.

COMMENTS

When the test inefficiency is not zero, the instantaneous unavailability continuously increases with time until a fully efficient test is performed (p=0) which is assumed here to occur at a scheduled shutdown (after approximately 1 year). As the test inefficiency increases, the undetected failure contribution increases and the periodic tests are less effective in maintaining an acceptable unavailability.

As shown in the figures, the average unavailability increases monotonically as the test inefficiency increases. From Equations A-18 and A-19, when p is non-zero, the average component unavailability $\bar{q}$ is approximately

$$\bar{q} \approx \frac{1}{2} \lambda pT + \frac{1}{2} \lambda(1-p)T_2 + q_1 \frac{\tau}{T_2} + q_2 \frac{T_R}{T_2} \qquad (1)$$

where T = one year for this problem (the time of the more efficient test). Since T is generally larger than the periodic test interval T_2, $\bar{q}$ thus increases as p increases which is observed in the figures.

Using Equation (1), the optimum test interval T_o is obtained by minimizing $\bar{q}$ with respect to T_2. Treating q_1 as being approximately independent of T_2 and ignoring the repair term, which generally has a small effect, the optimum test interval T_o is approximately[5]

$$T_o \approx \sqrt{\frac{2 q_1 \tau}{\lambda(1-p)}} \qquad (2)$$

---

[4]Since the reader may wish to recompute these examples, the results are given to more significant figures than would generally be used in practice.

[5]The unavailability q_1 will be approximately independent of T_2 if p_f or q_o is much larger than Q, as in this problem (see Equation A-14).

Figure D-1

Schematic for Examples 1, 2 and 3

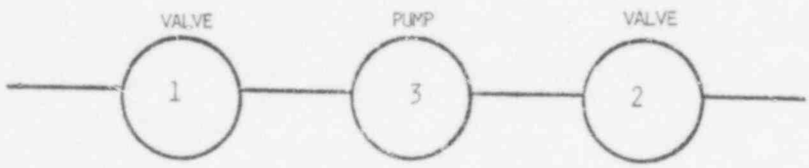


Figure D-2

Data Group Input for Example 1

```
TITLE
EXAMPLE 1.  TURBINE PUMP - TEST INEFFICIENCY SENSITIVITY
COMPONENTS
NEW
    1VALVE       .3    30          1.5     7     1
    2VALVE       .3    30          1.5     7     1
    3PUMP         3    30          1.5    19     1
    4DUMMY        0    15
   -1
PRINT
   -1
PLOT
    1
0.0       300.0
RUN
  1 TOTL               -8 CASE 1 - TEST INEFFICIENCY = 0
 -1
COMPONENTS
UPDATE
    1                                                      0.1
    2                                                      0.1
    3                                                      0.1
   -1
RUN
  1 TOTL               -8 CASE 2 - TEST INEFFICIENCY = .1
 -1
COMPONENTS
UPDATE
    1                                                      0.5
    2                                                      0.5
    3                                                      0.5
   -1
RUN
  1 TOTL               -8 CASE 3 - TEST INEFFICIENCY = .5
 -1
```

Figure D-3

SYSCOM Subroutine for Examples 1, 2, and 3

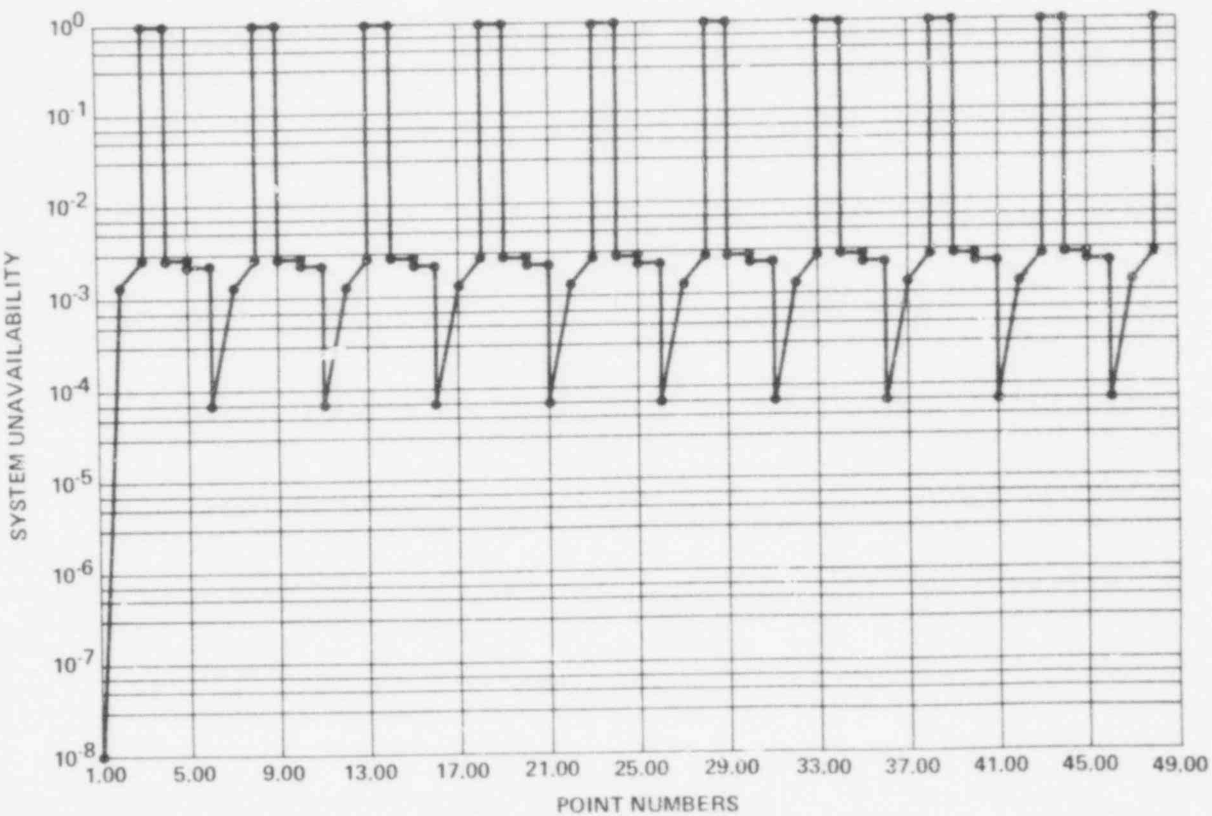
```
      SUBROUTINE SYSCOM(QC,QS,NSYS)
C
      DOUBLE PRECISION QC(1)
C
C
      QS=1.-(1.-QC(1))*(1.-QC(2))*(1.-QC(3))
      RETURN
C
C
      END
```

783 042

Figure D-4

Example 1. Test Inefficiency Sensitivity Study

Case 1. Test Inefficiency p=0.0
(average system unavailability = 3.39x10^{-3})

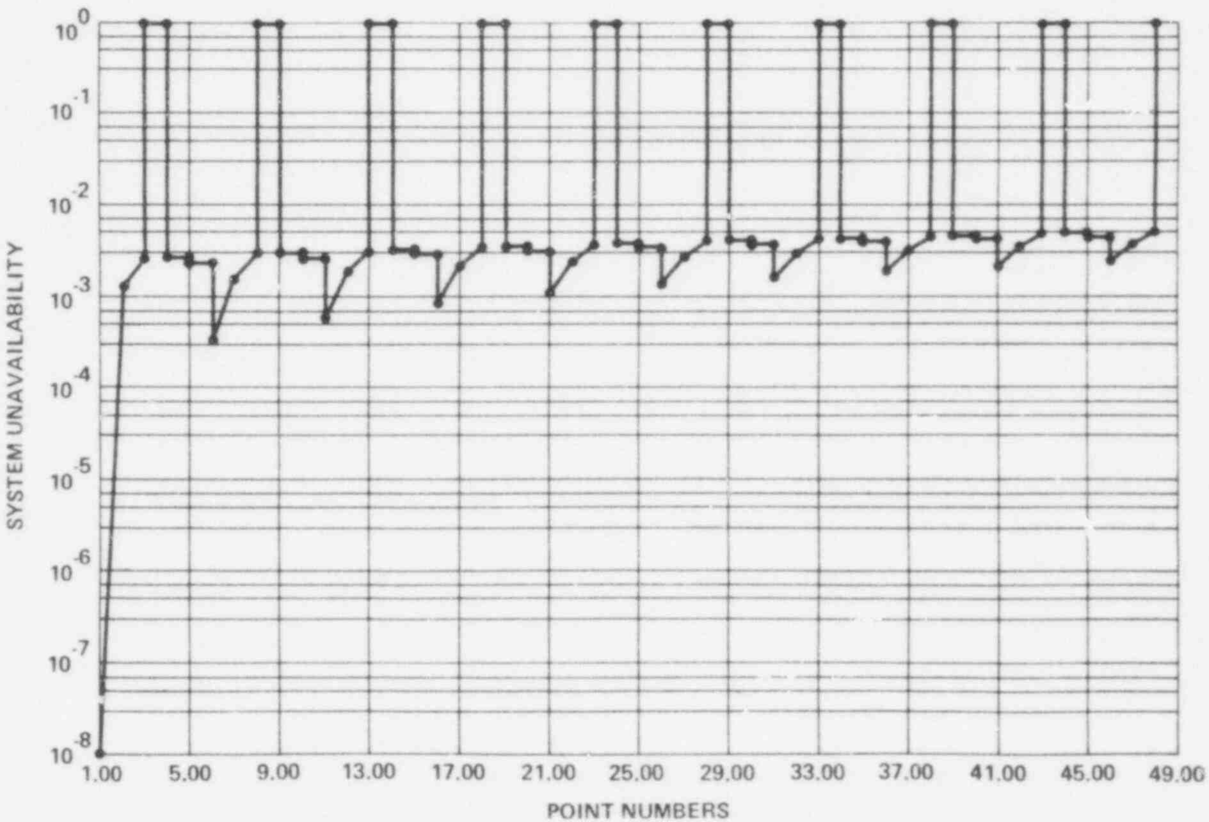


763 045

Figure D-5

Example 1. Test Inefficiency Sensitivity Study

Case 2. Test Inefficiency p=0.1
(average system unavailability = 3.53×10^{-3})

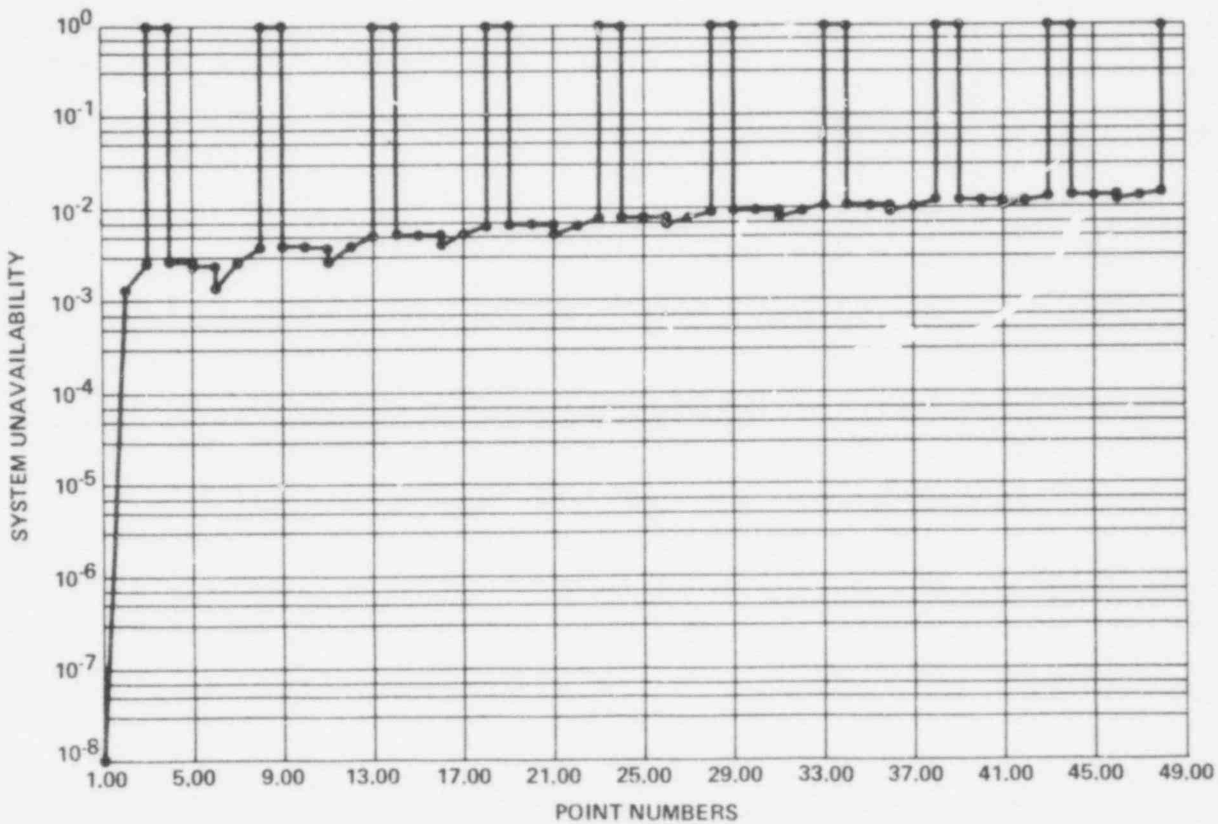


763 044

Figure D-6

Example 1. Test Inefficiency Sensitivity Study

Case 3. Test Inefficiency p=0.5
(average system unavailability = 4.83×10^{-3})



763 245

Figure D-7

Time Point Data for Example 1

EXAMPLE 1. TURBINE PUMP - TEST INEFFICIENCY SENSITIVITY

***** TIME POINT DATA *****

THE NUMBER OF POINTS GENERATED = 62
TOTAL TIME PERIOD IN HOURS (DEFAULT=1 YR) = 8760.000

THE TIME POINTS (IN HOURS) ARE PRINTED BELOW:

1 = 0.0	2 = 3.6000E+02	3 = 7.2000E+02	4 = 7.2150E+02	5 = 7.2850E+02
6 = 7.4050E+02	7 = 1.0800E+03	8 = 1.4400E+03	9 = 1.4415E+03	10 = 1.4485E+03
11 = 1.4605E+03	12 = 1.8000E+03	13 = 2.1600E+03	14 = 2.1615E+03	15 = 2.1685E+03
16 = 2.1805E+03	17 = 2.5200E+03	18 = 2.8800E+03	19 = 2.8815E+03	20 = 2.8885E+03
21 = 2.9005E+03	22 = 3.2400E+03	23 = 3.6000E+03	24 = 3.6015E+03	25 = 3.6085E+03
26 = 3.6205E+03	27 = 3.9600E+03	28 = 4.3200E+03	29 = 4.3215E+03	30 = 4.3285E+03
31 = 4.3405E+03	32 = 4.6800E+03	33 = 5.0400E+03	34 = 5.0415E+03	35 = 5.0485E+03
36 = 5.0605E+03	37 = 5.4000E+03	38 = 5.7600E+03	39 = 5.7615E+03	40 = 5.7685E+03
41 = 5.7805E+03	42 = 6.1200E+03	43 = 6.4800E+03	44 = 6.4815E+03	45 = 6.4885E+03
46 = 6.5005E+03	47 = 6.8400E+03	48 = 7.2000E+03	49 = 7.2015E+03	50 = 7.2085E+03
51 = 7.2205E+03	52 = 7.5600E+03	53 = 7.9200E+03	54 = 7.9215E+03	55 = 7.9285E+03
56 = 7.9405E+03	57 = 8.2800E+03	58 = 8.6400E+03	59 = 8.6415E+03	60 = 8.6485E+03
61 = 8.6605E+03	62 = 8.7600E+03			

763 046

As the test inefficiency p increases, the optimum test interval therefore increases and the component should be tested less frequently. The system unavailability can be sensitive to test inefficiencies particularly when the system is redundant and test inefficiencies compound one another (such as when the same test is performed on all similar redundant components).

763 047

2. EXAMPLE 2: TEST-CAUSED FAILURE SENSITIVITY STUDY

Purpose: To determine the unavailability effects of test-caused failures having probability p_f.

Input: The system model is the same as for Example 1. Figure D-8 shows the basic component input (p_f=0) and the change case input for p_f=0.1 and p_f=0.5.

Output: Figures D-9 through D-11 show the FRANTIC plots (MAG plots) corresponding to the different values of p_f; the one year average unavailabilities are included with the figures.

Comments

The computer run is similar in format to that of Example 1. It should be noted that Examples 1 and 2 could have been executed in one computer run (in fact all four examples could have been). Increases in the test-caused failure probability in general cause the test and repair contribution (q_1 and q_2) to increase. When the override unavailability (q_o) is 1, as in this problem, then only the repair contribution (q_2) increases. In addition to causing higher peaks in the instantaneous unavailability, the average unavailability also increases as p_f increases. As the test-caused failure probability increases from 0 to 0.5, the average system unavailability increases from 3.39×10^{-3} to 2.00×10^{-2}. Higher test-caused failure probabilities, e.g. p_f, J.1, can thus impact the system unavailability.

Figure D-8

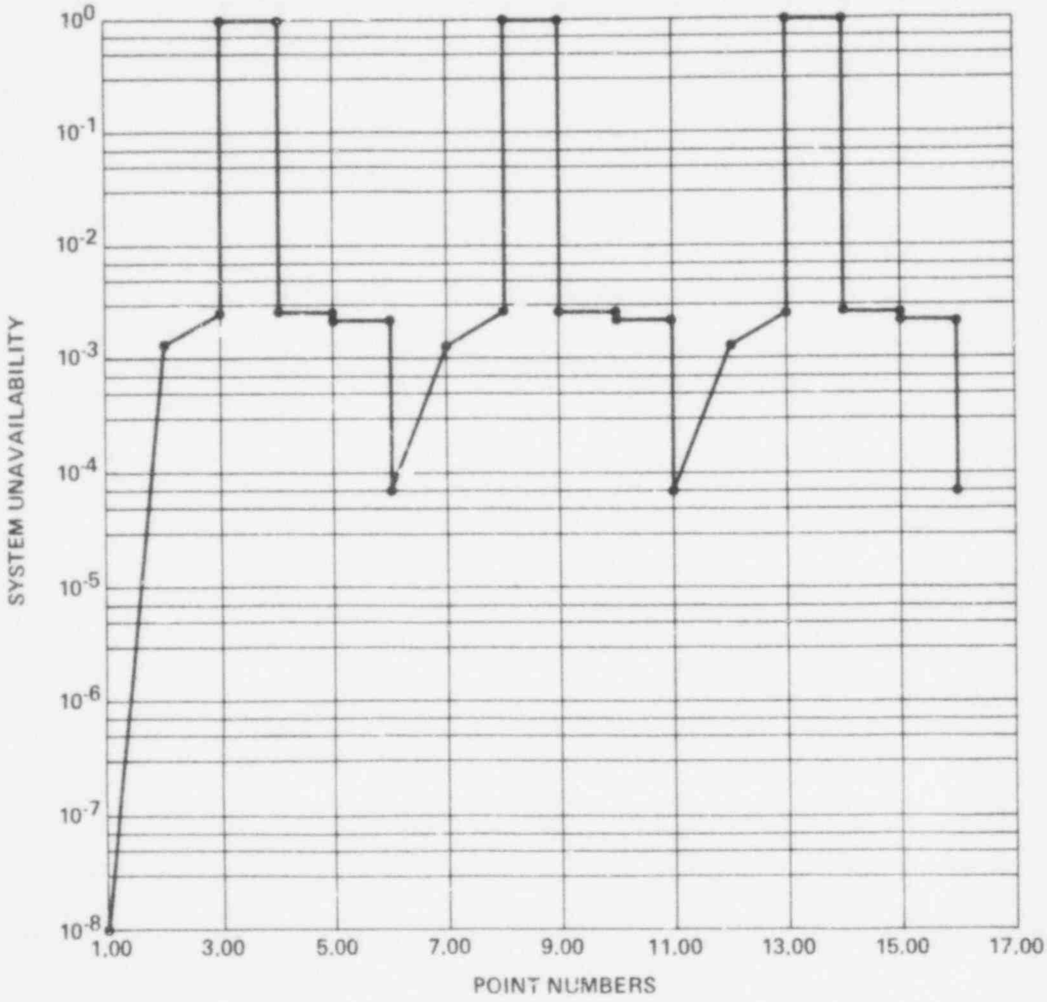
Data Group Input for Example 2

```
TITLE
EXAMPLE 2.  TURBINE PUMP - TEST-CAUSED FAILURES SENSITIVITY
COMPONENTS
NEW
     1VALVE        .3     30         1.5     7      1
     2VALVE        .3     30         1.5     7      1
     3PUMP          3     30         1.5    19      1
     4DUMMY         0     15
   -1
PRINT
     1
0.0        180.0
RUN
  1 TOTL                 -8 CASE 1 - PROBABILITY OF TEST-CAUSED FAILURE = 0
 -1
COMPONENTS
UPDATE
     1                                                  0.1
     2                                                  0.1
     3                                                  0.1
   -1
RUN
  1 TOTL                 -8 CASE 2 - PROBABILITY OF TEST-CAUSED FAILURE = .1
 -1
COMPONENTS
UPDATE
     1                                                  0.5
     2                                                  0.5
     3                                                  0.5
   -1
RUN
  1 TOTL                 -8 CASE 3 - PROBABILITY OF TEST-CAUSED FAILURE = .5
 -1
```

Figure D-9

Example 2: Test-Caused Failure Sensitivity Study

Case 1. Probability of Test-Caused Failure p_f =0.0
(average system unavailability = 3.39×10^{-3})



763 040

Figure D-10

Example 2. Test-Caused Failure Sensitivity Study

Case 2. Probability of Test-Caused Failure $p_{f_3} = 0.1$
(average system unavailability = 7.62×10^{-3})

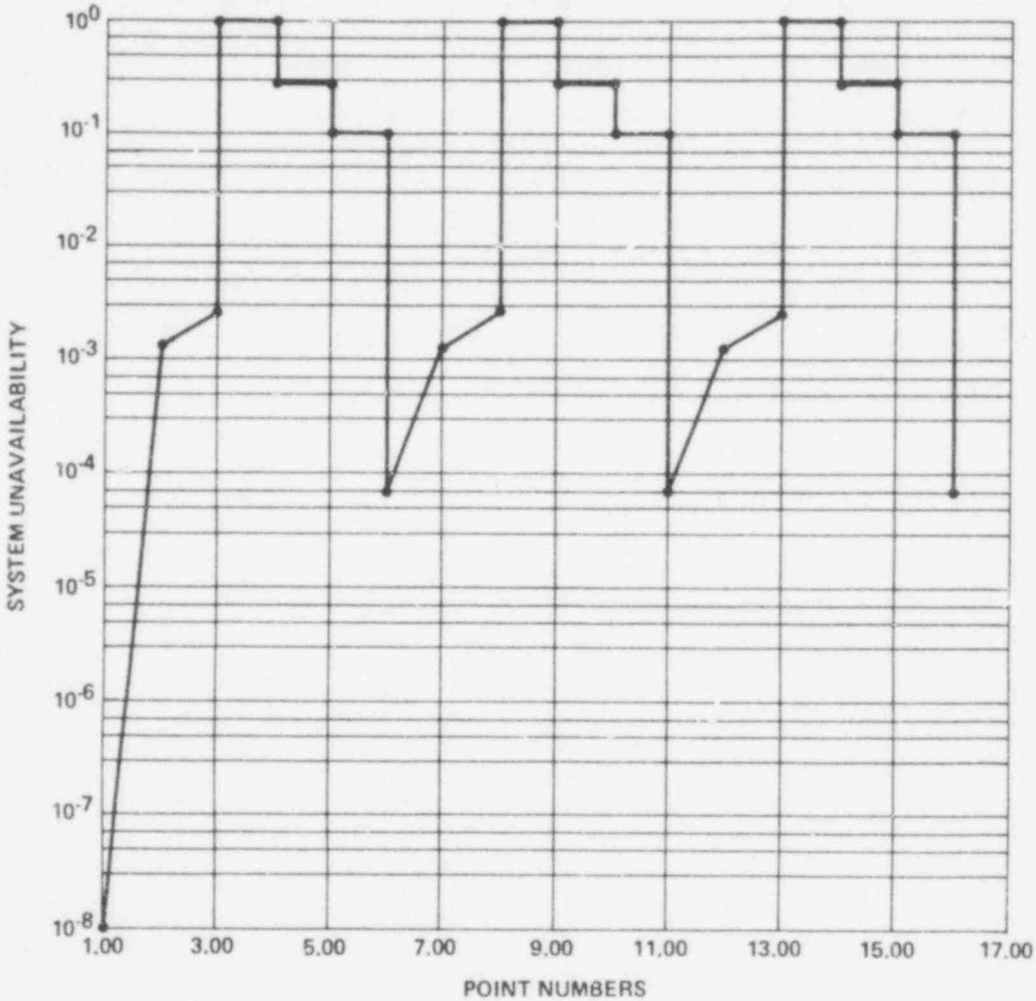
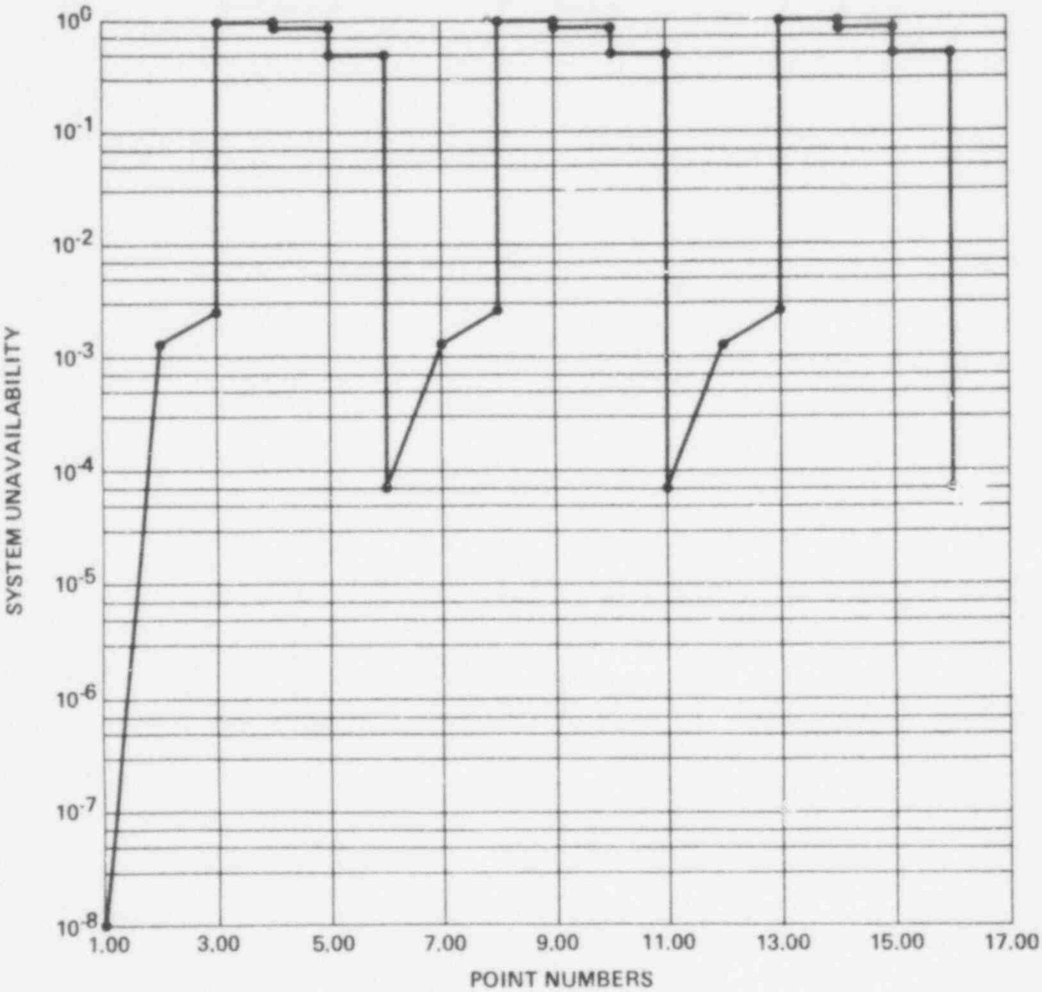


Figure D-11

Example 2. Test-Caused Failure Sensitivity Study

Case 3. Probability of Test-Caused Failure $p_{f_2} = 0.5$
(average system unavailability = 2.00×10^{-2})



763 051

3. EXAMPLE 3: TEST INTERVAL SENSITIVITY STUDY

Purpose: To determine the approximate, optimum component test intervals which minimize the average system unavailability.

Input: The system is again the same as for Example 1. Figure D-12 shows the basic component input and change case data for the different test intervals. (The same test interval is used for all components.)

Output: Figure D-13 shows the average system unavailability versus test interval obtained from the FRANTIC run.

Comments

In addition to obtaining time dependent behaviors, the FRANTIC code can be used to obtain average unavailabilities in which the time dependent information is suppressed, as in this problem. As Figure D-13 shows, the optimum test interval for this particular system is approximately 38 days, with different test intervals near the optimum causing little increase in the unavailability (i.e., the optimum region is fairly broad).

Many schemes may be used to determine optimum or near optimum test intervals and a simple one was used here. Referring to Equation (2) of Example 1, the approximate, optimum test interval T_o for a component is

$$T_o = \sqrt{\frac{2q_1\tau}{\lambda(1-p)}}$$

and if p is zero, Equation (2) becomes

$$T_o = \sqrt{\frac{2q_1\tau}{\lambda}}$$

Using component data and Equation A-14 for q_1, the value of T_o for each component can therefore be manually calculated using the above equation. The FRANTIC code can then be run to investigate different change case about these initial, optimum test interval values as was done here. Applicable test intervals or bounds on applicable test intervals which are near optimum and which satisfy practical considerations can thus be determined. When the system is more complex and more redundant than the one analyzed here, the system unavailability will depend not only on the test intervals but also on the way the tests are staggered. This will be illustrated in the next example.

763 052

Figure D-12

Data Group Input for Example 3

```
TITLE
EXAMPLE 3.  TURBINE PUMP - TEST INTERVAL SENSITIVITY
COMPONENTS
NEW
    1VALVE        .3     5         1.5     7     1
    2VALVE        .3     5         1.5     7     1
    3PUMP          3     5         1.5    19     1
    4DUMMY         0     5
   -1
RUN
  1 TOTL NONE NONE       CASE 1 - 5 DAY TEST INTERVAL
 -1
COMPONENTS
UPDATE
    1                   30
    2                   30
    3                   30
   -1
RUN
  1 TOTL NONE NONE       CASE 2 - 30 DAY TEST INTERVAL
 -1
COMPONENTS
UPDATE
    1                   38
    2                   38
    3                   38
   -1
RUN
  1 TOTL NONE NONE       CASE 3 - 38 DAY TEST INTERVAL
 -1
COMPONENTS
UPDATE
    1                   60
    2                   60
    3                   60
   -1
RUN
  1 TOTL NONE NONE       CASE 4 - 60 DAY TEST INTERVAL
 -1
COMPONENTS
UPDATE
    1                  180
    2                  180
    3                  180
   -1
RUN
  1 TOTL NONE NONE       CASE 5 - 180 DAY TEST INTERVAL
 -1
```

Figure D-13

Average System Unavailabilities for Five Test Intervals

Test Interval	One Year Average System Unavailability
5 days	1.26×10^{-2}
30 days	3.39×10^{-3}
38 days	3.19×10^{-3}
60 days	3.64×10^{-3}
180 days	8.06×10^{-3}

4. EXAMPLE 4: AUX-FEED SYSTEM ANALYSIS

Purpose: To determine the effects of different testing schemes on the instantaneous and average system unavailability.

Input: The system schematic is shown in Figure D-14. The system consists of two diesels in parallel with a pump; two valves are in series with the pump (the subsystem of the pump and two valves was analyzed in the previous examples). The model is a simplified version of one of the auxiliary feedwater system models given in WASH-1400;[6] the model here contains those major, active components which are periodically tested. One base case and four change cases are analyzed in the FRANTIC run. For the base case, the pump test interval is 30 days and the diesel test intervals are 60 days with the diesel tests being staggered; the pump test is assumed to be performed at the same time that a diesel test is performed. The four change cases study the effects of 1) test overrides on the diesel, 2) staggering the pump and diesel tests, 3) staggering the pump and diesel tests with test overrides on the diesels, and 4) staggering the pump and diesel tests with 60 day test intervals used for the pump. Figure D-15 shows the SYSCOM system function input. The basic component input for the computer run is shown in Figure D-16. Figures D-17 through D-19 depict the different testing schemes investigated.

Output: The FRANTIC MAG plots for the base case (Case 1), and four change cases (Cases 2-5), are shown in Figures D-20 through D-24. The times corresponding to the points in the plots are given in Figure D-25.

Comments

Additional output was generated by FRANTIC, i.e., tables, etc.; however, the MAG plots graphically illustrate the effects of the different testing schemes.

The base case testing scheme is depicted in Figure D-17. This testing scheme gives an average system unavailability of 6.37×10^{-5} and a peak instantaneous unavailability of 3.0×10^{-2} as illustrated in Figure D-20. The peak unavailability occurs 12 times a year, at the time of each pump test. For this base case, because one diesel is tested at the same time that the pump is, the instantaneous unavailability during the test is the unavailability of a single diesel (3.0×10^{-2}). Thus because of this testing scheme, a triply redundant system is reduced to a single failure system 12 times per year.

The effect of test overrides on the diesels (Case 2) was investigated by changing the diesel override unavailability (q_o) to 0.1, which represents a 90% probability of overriding the test and placing the diesels in operation if demanded. The base case testing scheme remained the same and all other component data remained the same. As shown in Figure D-21, the average system unavailability decreased to 1.11×10^{-5} and the peak unavailability decreased to 4.7×10^{-3}. As compared to the base case, the test overrides thus decreased the average unavailability by a factor of 5.8 and decreased the peak unavailability by a factor of 6.4.

For Case 3, no diesel override capability ($q_o = 1$) was again assumed as in the ba case, and instead only the testing times were changed so that the pump tests were staggered with the diesel tests. The diesel-pump staggering scheme is depicted in Figure D-18. For this new testing scheme, the average system unavailability is 2.46×10^{-6} and the peak unavailability is 6.9×10^{-4} as shown in Figure D-22. As compared to the base case, the new testing scheme decreased the average unavailability by a factor of 25.8 and decreased the peak by a factor of 43.5.

In WASH-1400, the diesels were included as part of the aux-feed system model because they were in the same accident sequence (i.e., the same event tree sequence). The above results of Case 3 show the beneficial effect of staggering tests not only within a subsystem (staggering between diesels) but across subsystems within the same accident sequence (pump test staggered between the diesel tests). The diesel-pump test staggering, involving test procedure changes, resulted in a greater availability improvement than the diesel override change case (Case 2), which might involve design changes. Even if only the peak were

---

[6] Appendix II, Page II-109, Case d., Loss of Net (Start + 8 hours).

763 054

Figure D-14

Block Diagram for Example 4

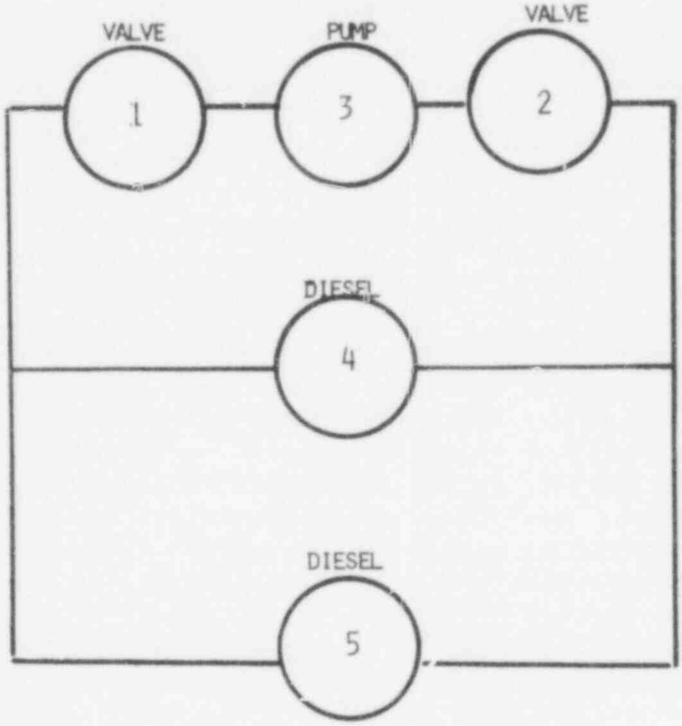


Figure D-15

SYSCOM Subroutine fc~ Example 4

```
      SUBROUTINE SYSCOM(QC,QS,NSYS)
C
      DOUBLE PRECISION QC(1)
C
C
      QS=(1.-(1.-QC(1))*(1.-QC(2))*(1.-QC(3)))*QC(4)*QC(5)
      RETURN
C
C
      END
```

763 055

Figure D-16

Data Group Input for Examp`e 4

```
TITLE
EXAMPLE 4.  AUX-FEED SYSTEM ANALYSIS
COMPONENTS
NEW
    1VALVE       .3    30          1.5     7     1
    2VALVE       .3    30          1.5     7     1
    3PUMP         3    30          1.5    19     1
    4DIESEL      42    60    30    1.5    21     1
    5DIESEL      42    60          1.5    21     1
    6DUMMY        0    15
  -1
PRINT
    1
210.0      240.0
PLOT
    2
0.0        120.0      210.0      240.0
RUN
  1 TOTL MAG  LOG     -9 CASE 1 - PUMP-30 DAYS, DIESELS-NO OVERRIDE,NO STAGGERING
 -1
COMPONENTS
UPDATE
    4                                            0.1
    5                                            0.1
   -1
RUN
  1 TOTL MAG  LOG     -9 CASE 2 - PUMP-30 DAYS, DIESELS-OVERRIDE,NO STAGGERING
 -1
COMPONENTS
UPDATE
    4                       15                   1
    5                       45                   1
   -1
RUN
  1 TOTL MAG  LOG     -9 CASE 3 - PUMP-30 DAYS, DIESELS-NO OVERRIDE, STAGGERED
 -1
COMPONENTS
UPDATE
    4                                            0.1
    5                                            0.1
   -1
RUN
  1 TOTL MAG  LOG     -9 CASE 4 - PUMP-30 DAYS, DIESELS-OVERRIDE,STAGGERED
 -1
COMPONENTS
UPDATE
    1                 60    30
    2                 60    30
    3                 60    30
    4                                            1
    5                                            1
   -1
PRINT
    1
210.0      270.0
PLOT
    2
0.0        120.0      210.0      270.0
RUN
  1 TOTL MAG  LOG     -9 CASE 5 - PUMP-60 DAYS, DIESELS-NO OVERRIDE,STAGGERED
```

763 056

Figure D-17

Testing Scheme Illustration for the Base Case

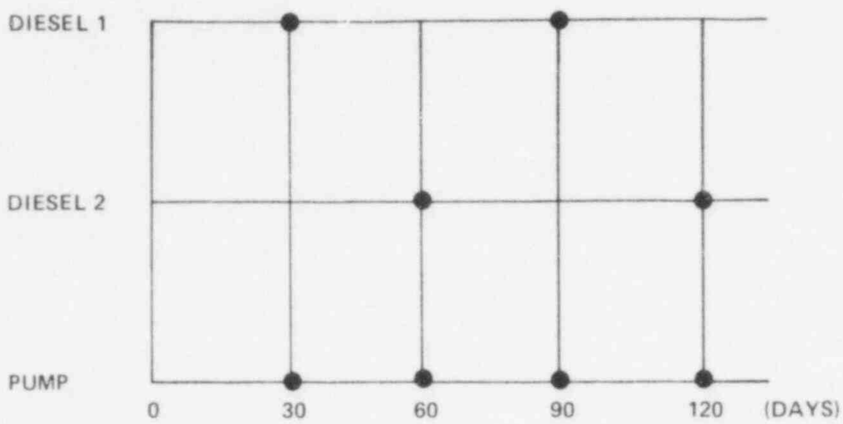


Figure D-18

Testing Scheme Illustration for Change Case 3

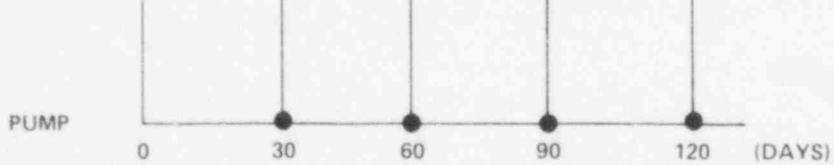


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Figure D-19

Testing Scheme Illustration for Change Case 5

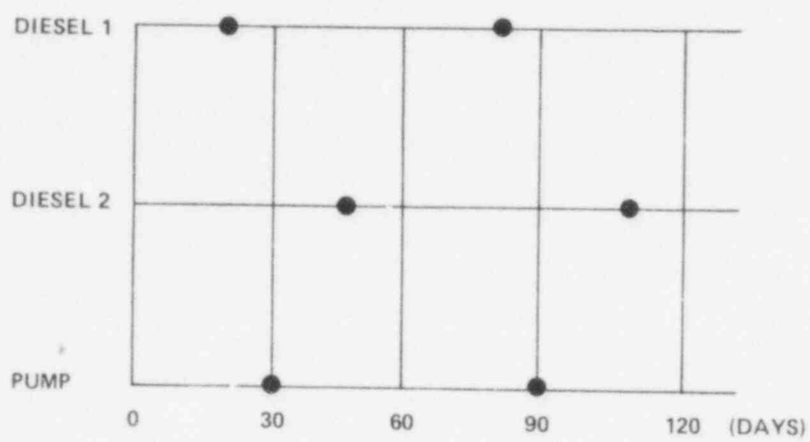
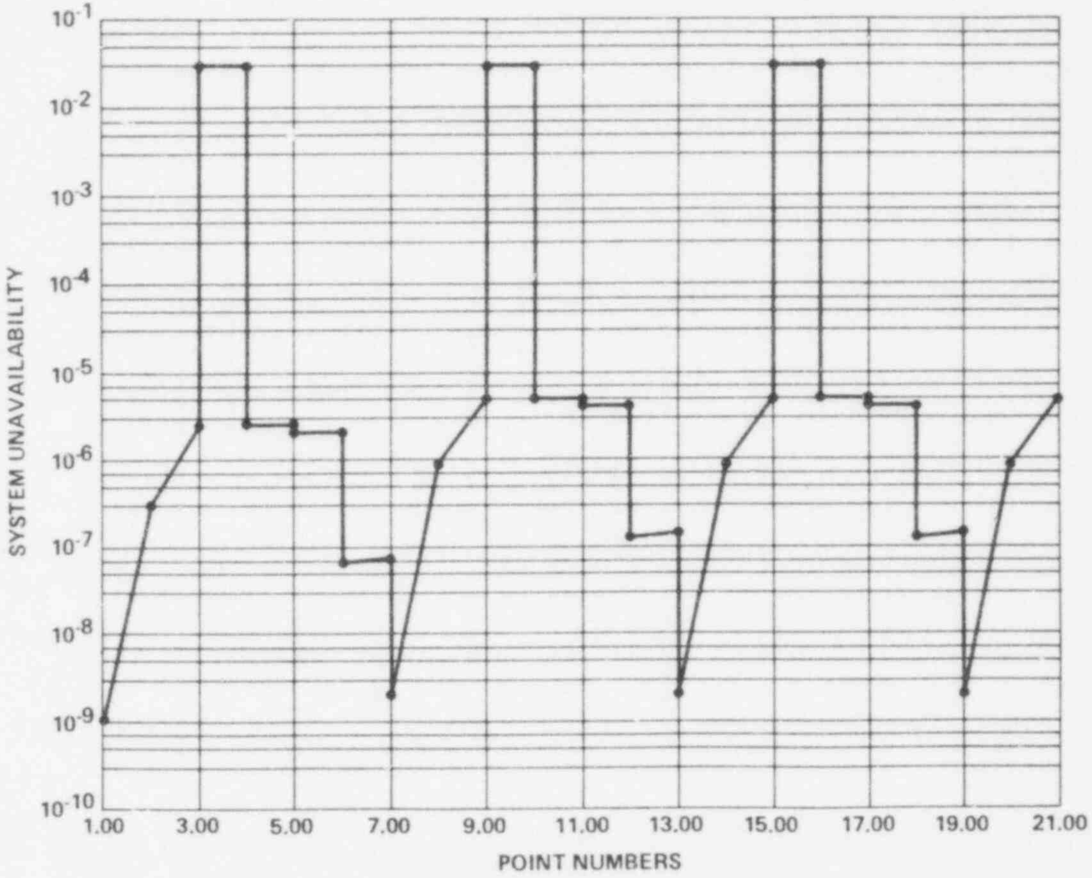


Figure D-20

Example 4. Aux-Feed System Analysis

Case 1. Base Case
(average system unavailability = 6.37×10^{-5})



763 059

Figure D-21

Example 4. Aux-Feed System Analysis

Case 2. Diesel Overrides
(average system unavailability = 1.11×10^{-5})

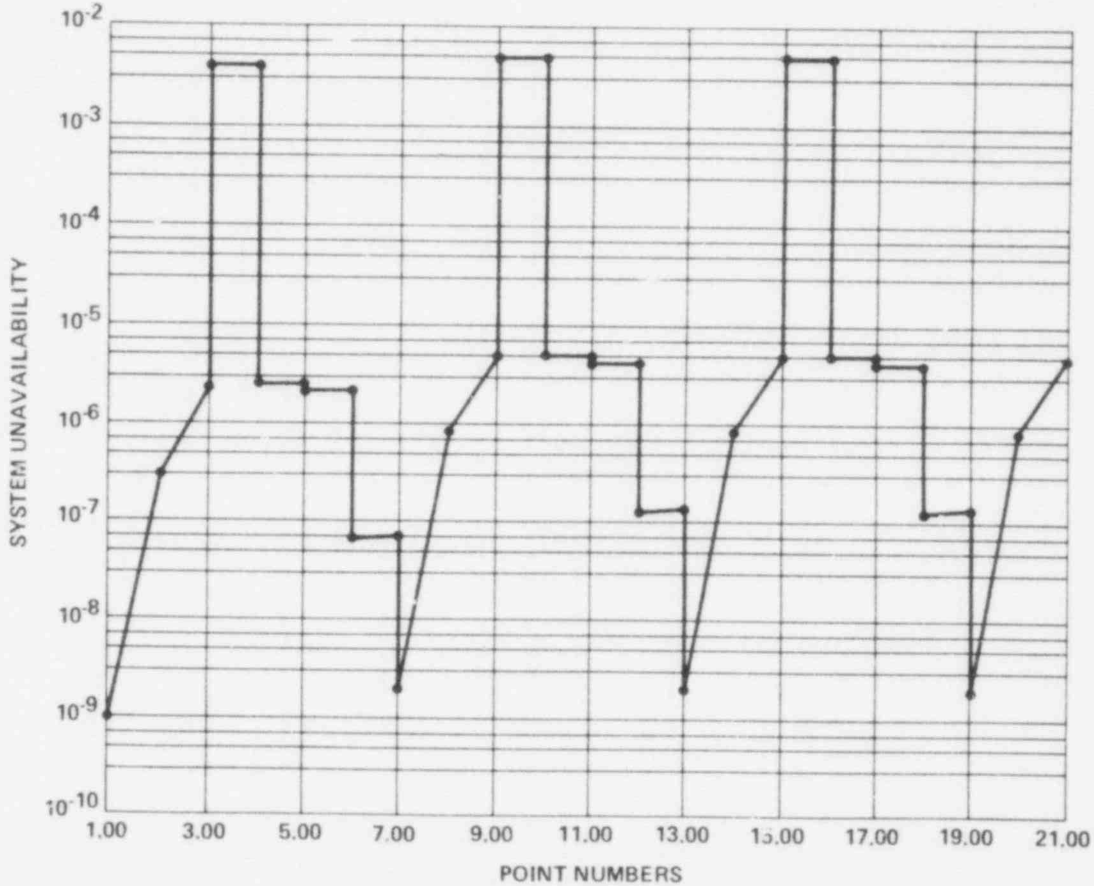


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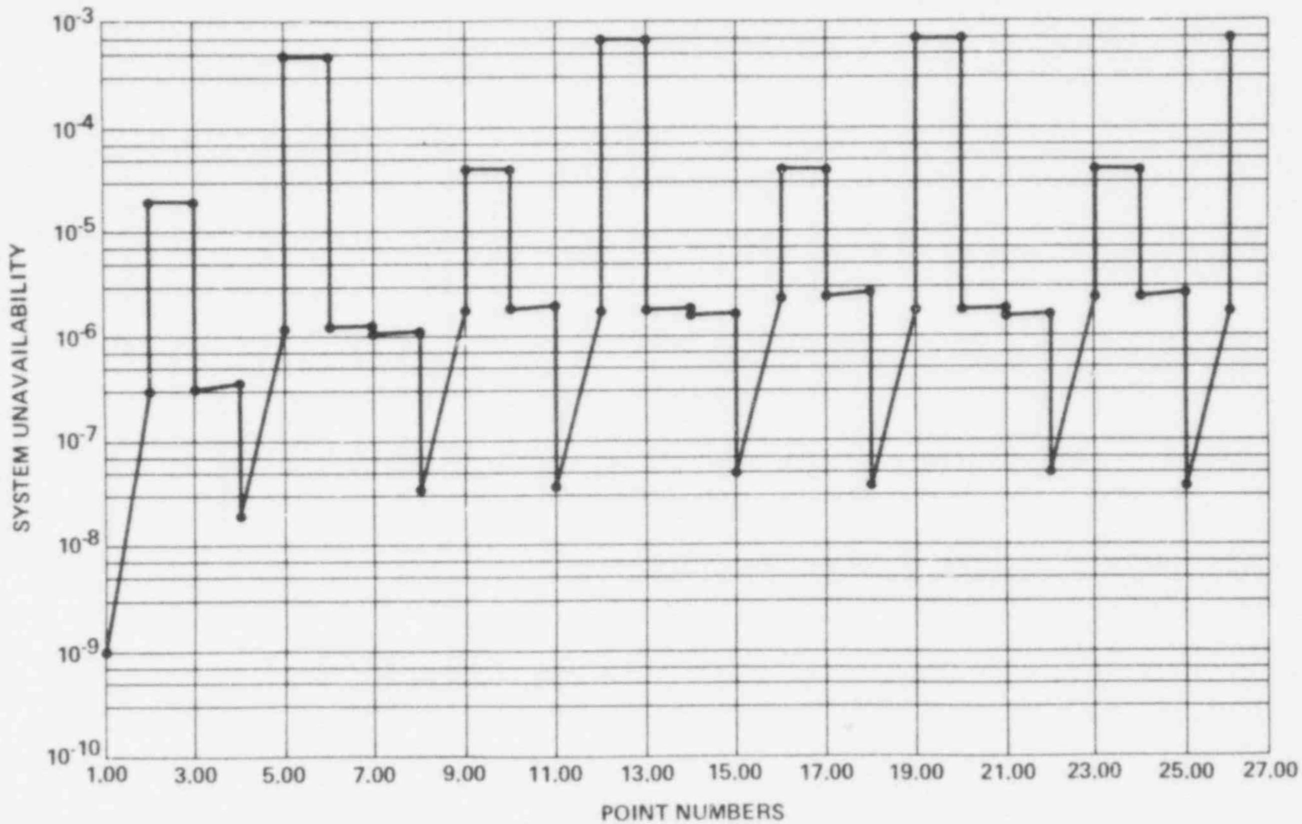
Figure D-22

Example 4. Aux-Feed System Analysis

Case 3. 30 Day Pump Staggering
(average unavailability = 2.46×10^{-6})

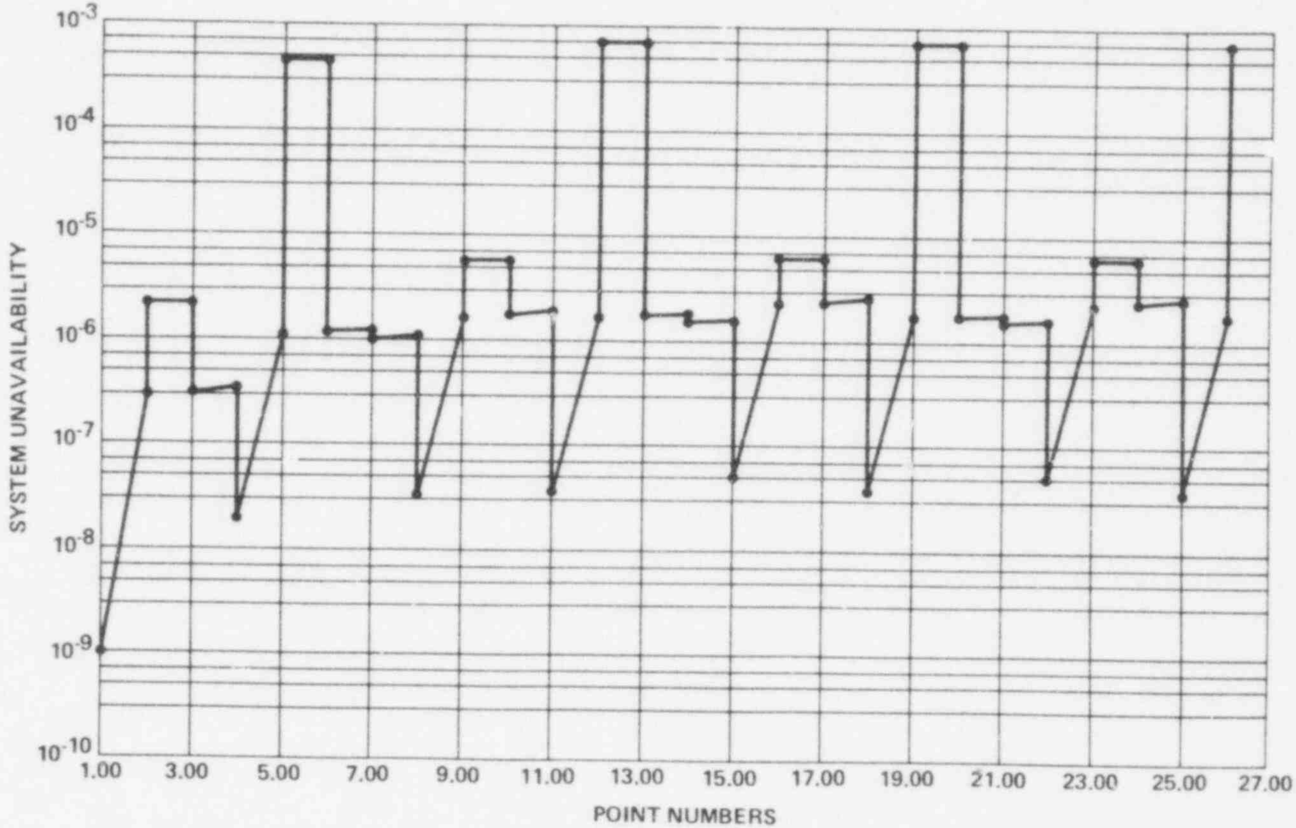


763 061

Figure D-23

Example 4. Aux-Feed System Analysis

Case 4. Diesel Overrides and 30 Day Pump Staggering
(average system unavailability = 2.40×10^{-6})



763 062

Figure D-24

Example 4. Aux-Feed System Analysis

Case 5. 60 Day Pump Staggering
(average system unavailability = 2.77×10^{-6})

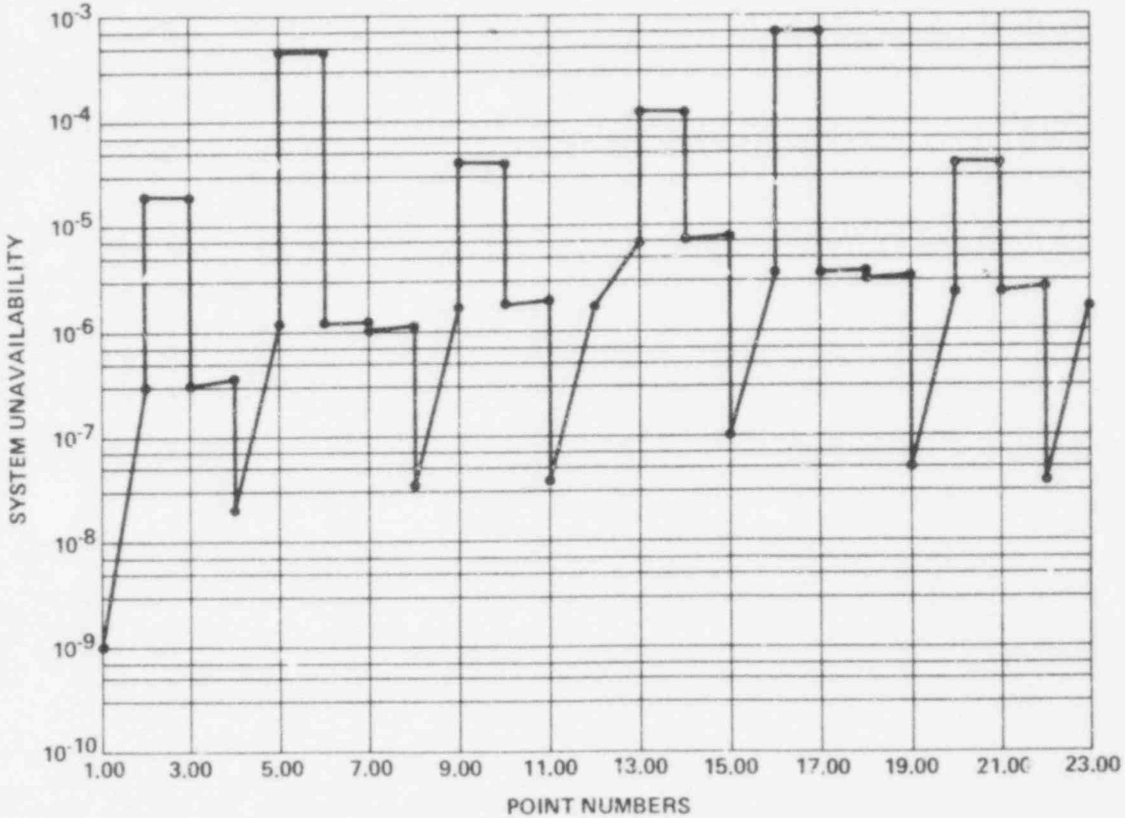


Figure D-25

Time Points for Example 4

Cases 1 and 2

SYSTEM UNAVAILABILITIES BETWEEN 210.00 AND 240.00 DAYS:

POINT NUMBER	TIME (DAYS)	TIME (HOURS)	UNAVAIL AT T-EPSILON	UNAVAIL AT T+EPSILON	UNAVAIL. INCREMENT	PERCENT OF TOTAL	AREA TYPE
39	2.1000E+02	5.0400E+03		3.0177E-02			
40	2.1006E+02	5.0415E+03	3.0240E-02	4.8125E-06	6.2934E-05	97.3381	T
41	2.1035E+02	5.0485E+03	4.8593E-06	4.0643E-06	4.7016E-08	0.0727	R
42	2.1085E+02	5.0605E+03	4.1449E-06	1.2914E-07	6.8410E-08	0.1058	R
43	2.1094E+02	5.0625E+03	1.4312E-07	2.0752E-09	3.7815E-10	0.0006	R
44	2.2500E+02	5.4000E+03	8.8007E-07	8.8007E-07	2.0675E-07	0.3198	
45	2.4000E+02	5.7600E+03	4.7141E-06	3.0177E-02	1.3985E-06	2.1631	

Cases 3 and 4

SYSTEM UNAVAILABILITIES BETWEEN 210.00 AND 240.00 DAYS:

POINT NUMBER	TIME (DAYS)	TIME (HOURS)	UNAVAIL AT T-EPSILON	UNAVAIL AT T+EPSILON	UNAVAIL. INCREMENT	PERCENT OF TOTAL	AREA TYPE
47	2.1000E+02	5.0400E+03		6.8204E-04			
48	2.1006E+02	5.0415E+03	6.8584E-04	1.7943E-06	1.4249E-06	54.5623	T
49	2.1035E+02	5.0485E+03	1.8410E-06	1.5398E-06	1.7671E-08	0.6767	R
50	2.1085E+02	5.0605E+03	1.6130E-06	5.0256E-08	2.6273E-08	1.0061	R
51	2.2500E+02	5.4000E+03	2.3526E-06	3.8939E-05	5.6650E-07	21.6929	
52	2.2506E+02	5.4015E+03	3.9184E-05	2.3836E-06	8.1378E-08	3.1162	T
53	2.2594E+02	5.4225E+03	2.5962E-06	3.7643E-08	7.2622E-08	2.7809	R
54	2.4000E+02	5.7600E+03	1.7635E-06	6.8204E-04	4.2214E-07	16.1649	

Case 5

SYSTEM UNAVAILABILITIES BETWEEN 210.00 AND 270.00 DAYS:

POINT NUMBER	TIME (DAYS)	TIME (HOURS)	UNAVAIL AT T-EPSILON	UNAVAIL AT T+EPSILON	UNAVAIL. INCREMENT	PERCENT OF TOTAL	AREA TYPE
38	2.1000E+02	5.0400E+03		6.8204E-04			
39	2.1006E+02	5.0415E+03	6.8584E-04	3.5699E-06	7.1244E-07	23.0747	T
40	2.1035E+02	5.0485E+03	3.6629E-06	3.0598E-06	1.7580E-08	0.5694	R
41	2.1085E+02	5.0605E+03	3.2000E-06	5.0256E-08	2.6082E-08	0.8448	R
42	2.2500E+02	5.4000E+03	2.3526E-06	3.8939E-05	2.8325E-07	9.1740	
43	2.2506E+02	5.4015E+03	3.9184E-05	2.3836E-06	4.0689E-08	1.3178	T
44	2.2594E+02	5.4225E+03	2.5962E-06	3.7643E-08	3.6311E-08	1.1760	R
45	2.4000E+02	5.7600E+03	1.7635E-06	1.7635E-06	2.1107E-07	6.8362	
46	2.5500E+02	6.1200E+03	7.0748E-06	1.1710E-04	1.1048E-06	35.7820	
47	2.5506E+02	6.1215E+03	1.1751E-04	7.1481E-06	1.2219E-07	3.9575	T
48	2.5594E+02	6.1425E+03	7.4995E-06	1.0874E-07	1.0681E-07	3.4592	R
49	2.7000E+02	6.4800E+03	3.5293E-06	6.8204E-04	4.2634E-07	13.8083	

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decreased and the average unavailability did not change, the diesel-pump staggering would be considered a test improvement because the system is never reduced to a single failure system with the diesel-pump test staggering.

For Case 4, Figure D-23 shows the effect of including test overrides on the diesels, using the diesel-pump staggering as in the second change case. The additional improvement is slight; the average unavailability decreases from 2.46×10^{-6} to 2.40×10^{-6} and the peak unavailability is not changed, remaining at 6.9×10^{-4} (the peak instantaneous unavailability arises from the pump test and not the diesel tests). This analysis shows that diesel test overrides have small effect when the pump test is staggered with the diesel tests.

The last change case, Case 5, uses the diesel-pump staggering concept but increases the pump test interval to 60 days. This modified testing scheme is illustrated in Figure D-19. As compared to the 30 day pump test interval (the second change case), when 60 days are used, the average unavailability increases slightly from 2.46×10^{-6} to 2.77×10^{-6} and the peak unavailability remains at 6.9×10^{-4} (Figure D-24). There are now 6 peaks instead of 12 because of the less frequent testing. These results show that staggering of the diesel and pump tests allow less testing to be performed on the pumps with little increase in the average unavailability. Moreover, the reduction in the number of peaks is a beneficial effect.

The above analyses, though only performed on a simple block diagram model, show the significant effects that different testing procedures can have. The analyses show that the times at which different components are tested can have a large impact on the peak and average system unavailability which are attained. By improving the testing schemes, the system unavailability can be significantly decreased, or less testing may need to be done.

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