HP 1000 Real-Time Computers

HEWLETT PACKARD

Hardware Reliability Modeling for Systems Using Dynamic Redundancy

Application Note 414

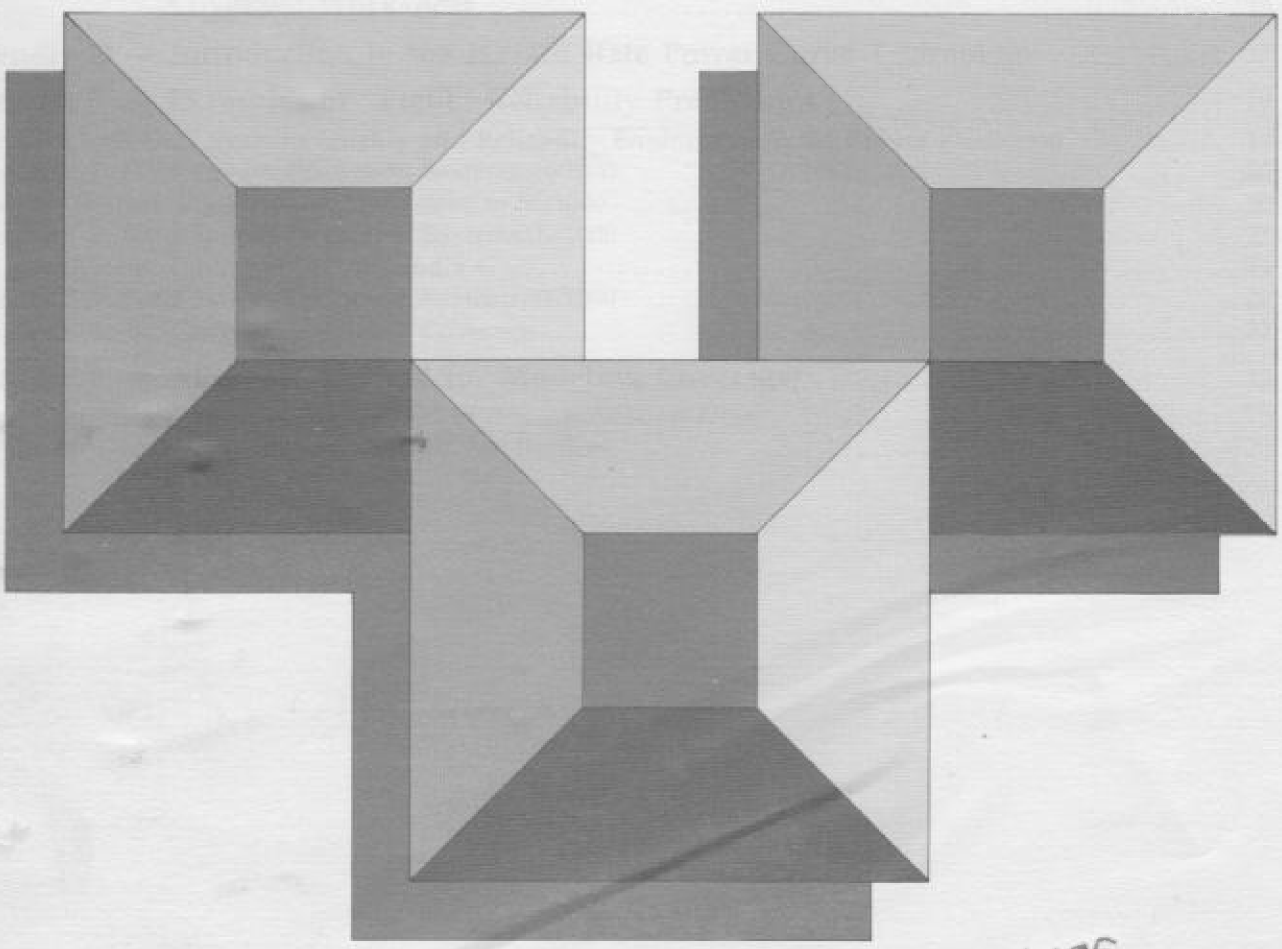


Table of Contents

Chapter I
Overview

Introduction

This Application Note presents a disciplined method for developing and presenting meaningful Hardware Reliability Information on systems, like the Hewlett-Packard Systemsafe/1000, using dynamic redundancy.

Systemsafe/1000 components in a typical configuration are used as the system example for this note. Systemsafe/1000 is a combined hardware and software package that provides components for dynamically redundant systems which provide excellent protection against hardware failure.

Dynamic Redundancy consists of automatic detection of most hardware failures combined with dynamic reconfiguration of available units to continue system operation with no detectable impact on outputs from application programs running at time of failure.

The Reliability Modeling Method is based on the Hazard Rate Power Curve Technology (HRPCT) developed at Hewlett-Packard in 1974 by Data Systems Quality & Reliability Engineering. This method is well proven and has numerous advantages over conventional methods for reliability prediction and measurement. Appendix D is an introduction to HRPCT and includes the basic formulas used.

This application note bridges the gap between conventional methods for developing and presenting reliability information and the real world where failure rate and MTBF are not constant values.

It provides system designers with a tool for making more accurate determination of the value of redundancy as expressed in number of system failures over any elapsed time period based on the interval used for computing probabilities of survival or failure.

Conventional methods assume a constant failure rate model and do not provide results that correlate with real-time experience. HRPCT is an easily used methodology that models the variable failure rate.

Appendix E presents Hardware Reliability Information for comparing the benefits of redundant systems and the impact of coverage; and Appendix E also shows the importance of establishing valid coverage factors. Coverage determines the degree to which it is possible to realize the full advantage of redundancy. Appendix F explains another approach to modeling coverage.

Systemsafe/1000 Reliability Information Summary

The following table summarizes reliability results as they apply to the Systemsafe/1000 configuration which was chosen as an example.

System Type	System Hardware Average MTBF		Availability Using
	Over 3 Months	Over 3 Years	MTTR = 24 hours over 3 years
Systemsafe/1000 with conventional 100%coverage **Appendix E-3**	52,967 hours 6.0 years	121,613 hours 13.9 years	99.98%
Systemsafe/1000 with coverage per Appendix C **Appendix E-2**	21,528 hours 2.5 years	49,428 hours 5.6 years	99.95%
Simplex equivalent to Systemsafe/1000 **Appendix E-1**	2,620 hours 0.3 years	6,016 hours 0.7 years	99.60%

Chapter II
Developing Reliability Information

Overview

This Application Note provides details for the 10 basic steps involved in developing Hardware Reliability Information on Dynamically Redundant Systems such as Systemsafe/1000. The material is intended to assist individuals in preparing reliability information customized for specific applications and with probability based on a stated Mean-Time-To-Repair of a failing unit.

The examples used in this Application Note do not necessarily represent typical Systemsafe/1000 applications.

The Ten Basic Steps for Developing Reliability Information

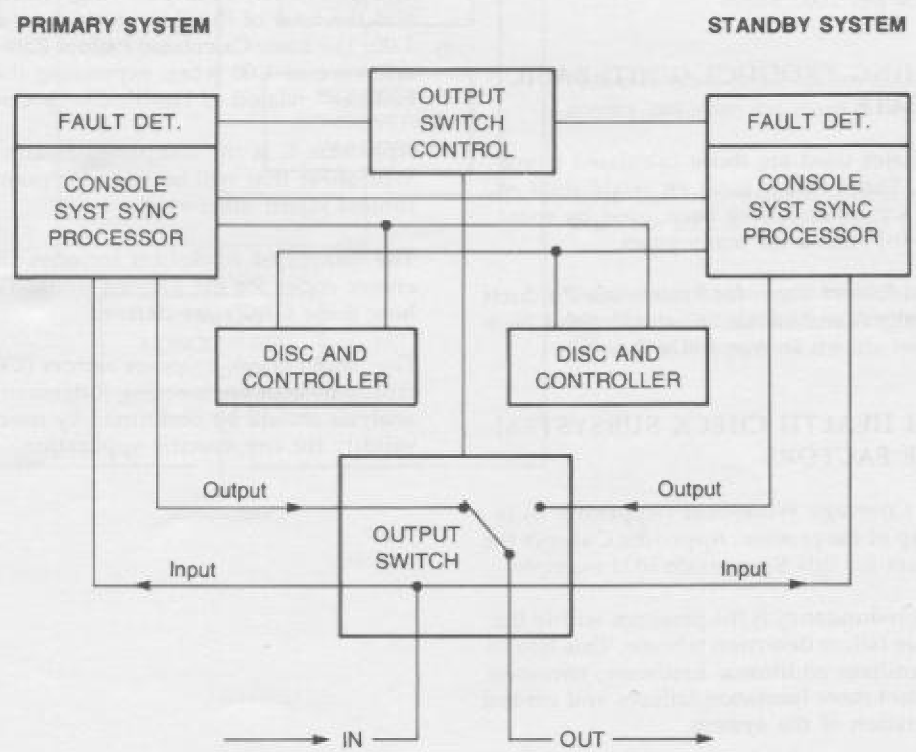
- Prepare Functional Block Diagram
- Define hardware products (units) required
- Establish product (unit) Basic Failure Rates
- Establish Health Check Subsystem Coverage Factors
- Prepare Reliability Model Logic Diagram
- Allocate Failure Rates to Reliability Logic Model
- Review of reliability mathematics used
- Calculate Basic Failure Rate/MTBF for Redundant System
- Establish system HRPCT Integration Factors
- Calculate desired Reliability Information

1. PREPARE A FUNCTIONAL BLOCK DIAGRAM

Shown below is the Systemsafe/1000 Functional Block Diagram.

Systemsafe/1000 implements the principles of Dynamic Redundancy. Two standard E or F-Series computers function as primary or standby CPUs. While executing the same application programs, synchronized by a common clock, both CPUs read data from external devices and each maintains its own duplicated data base on disc. However only the primary CPU is permitted to write data to external devices via the I/O switch modules. Operation of both CPUs is continually checked by the fault detection subsystem which activates the I/O switch if a failure in the primary CPU is detected. Once switched, the operating CPU becomes the primary and remains so until it has a failure, at which time output is switched back to the standby CPU.

The Disc Subsystem and Fault Control Memory employ the principles of masking redundancy. With masking redundancy, no hardware units are reconfigured to maintain system operation. To assure continuing high reliability from these subsystems, the fault detection subsystem must detect and report both disc and memory failures.



2. DEFINE THE HARDWARE PRODUCTS REQUIRED

Specific hardware is a design decision related to an individual application requirement. This note uses the basic Systemsafe hardware products which are listed below with their Calculated Failure Rates. The basis for the calculated failure rates is covered in Step 3.

Systemsafe/1000 Hardware Products

Unit Ref.	Model Number	Product Description	Failure* Rate
1	13037C	Disc Ctlr.	9.80008
2	7920A	Disc	17.52848
3	13175B	Disc I/F	1.59488
4	13178C	Disc I/F	2.43000
5	2645A	Terminal	16.91189
6	+007	Term Mini-Crtdg	6.88895
7	12966A	Term I/F	2.35859
8	2117F	CPU & Pwr Sply	25.54957
9	12789M	2Mb FC Mem	8.92408
10	93770A	Clock/Sync	1.33625
11	12791A	FEM	0.88246
12	12824A	VIS	0.25704
13	12897B	DCPC	1.88387
14	12991B	Pwr F1/Rcvy	3.28480
15	12992B	Disc Ldr ROM	0.08160
16	12992C	Term Ldr ROM	0.08568
17	29402C	Cab/Pwr Dstr	0.34564
18	93768A	W Dg Timer	1.42384
19	12566C	Wd Timer I/F	1.10573
20	93550A	Sw Case/Pwr	1.79308
21	Opt 46	Switch Control	1.12453
22	Opt 16	Output Switch	.32879

* Failure Rates in % per 1000 hours

3. ESTABLISHING PRODUCT (UNIT) BASIC FAILURE RATE

The Basic Failure Rates used are those calculated using RADC-II Methods. These values have an established relationship to field actuals and have been used by some divisions of Hewlett-Packard for many years.

RADC-II Calculated Failure Rates for Systemsafe Products are listed in Appendix A and are also on the Health Check Coverage Worksheet shown in Appendix B.

4. ESTABLISH HEALTH CHECK SUBSYSTEM COVERAGE FACTORS

The Health Check Coverage Worksheet (Appendix B) is started with this step of the process. Appendix C shows the completed worksheet for this Systemsafe/1000 example.

The key to dynamic redundancy is the presence within the system of a hardware failure detection scheme. This Health Check Subsystem utilizes additional hardware, firmware and software to detect most hardware failures and control dynamic reconfiguration of the system.

In this step, the term "unit" is general and applies to a complete product, an assembly within the product, or to some fractional part of either.

Prior to designing health check features, each "unit" in the system must be evaluated to identify those "units" where a failure without dynamic reconfiguration will cause a system hardware failure. These are defined as "Critical Failure Units".

Following this, identify "units" which can fail without dynamic reconfiguration and not cause system failure. These are defined as "Non Critical Units".

The next step is to design the Health Check Subsystem to cover as many of the "Critical Failure Units" as is economically feasible.

When Health Check Design has been completed, Coverage Factors must be established for each unit of hardware in the system. The Coverage Factor assigns an appropriate fraction of the basic failure rate to the applicable group in the reliability logic model.

This is done using the Health Check Coverage (HCC) Worksheet. For each hardware unit on the HCC Worksheet, enter a Coverage Assignment Factor to one or more of the following codes.

CFC = Fraction of Critical Unit Failures covered by Health Check.

CFN = Fraction of Critical Unit Failures not found by Health Check.

NCF = Fraction of any Unit Failures not covered by Health Check which can fail without causing the system to fail.

The factors may be any two digit fraction from .00 to 1.00, and the total of the three factors on any unit must equal 1.00. The basic Calculated Failure Rate for a unit serves as a reference of 1.00 when expressing the "Fraction of Unit Failures" related to Health Check Coverage.

Appendix C is the completed Health Check Coverage Worksheet that will be used for examples from here on (unless stated otherwise).

The completed worksheet includes GRC's or group reference codes for the various units. The next step shows how these GRC's are derived.

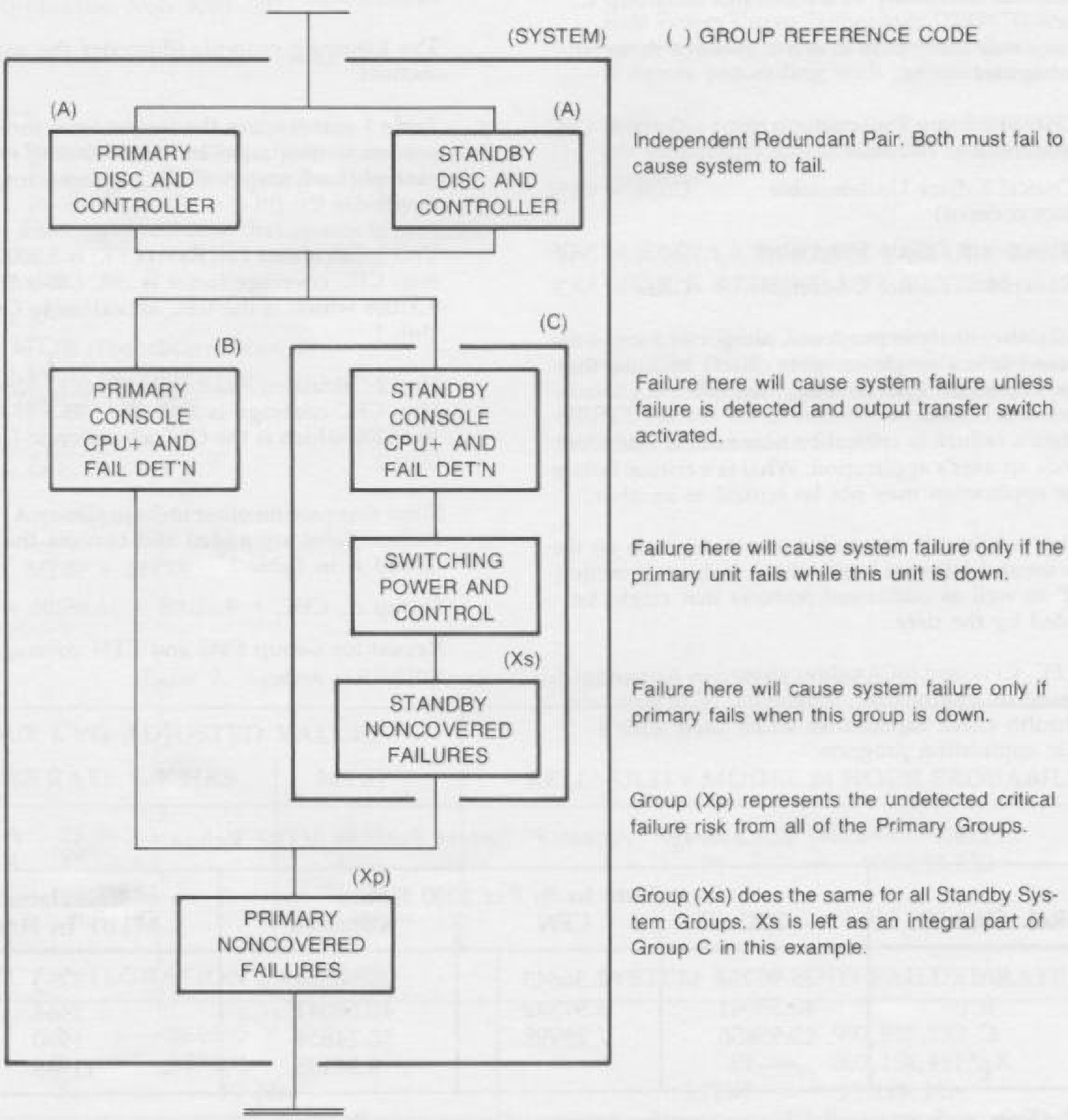
The health check coverage factors (CFC, CFN, & NCF) represent best engineering judgement. However, careful analysis should be performed by users to determine their validity for any specific application.

5. PREPARE RELIABILITY MODEL LOGIC DIAGRAM

The Systemsafe/1000 Reliability Model Logic Diagram to follow is used to assign each unit on the Health Check Coverage Worksheet (Appendix B) to one of the groups in the Reliability Model Logic Diagram. Enter the Group Reference Code (GRC) in the Health Check Coverage Worksheet as shown in Appendix C.

For the Systemsafe/1000 configuration, the appropriate GRC factors have been entered in the completed worksheet shown in Appendix C.

Systemsafe/1000 Reliability Model Logic Diagram



6. ALLOCATE FAILURE RATES TO RELIABILITY LOGIC MODEL GROUPS

This is done using the completed HCC Worksheet (Appendix C).

a. Review Group Reference Codes for each unit type. These codes identify the hardware unit with the Reliability Model Group to which it belongs. Some unit types may belong in more than one group. This is indicated by the number of group reference codes in the GRC column of the worksheet.

For example, 2117F, which is the CPU and Power Supply, was assigned a Group Reference Code of BC. That means that the primary 2177F belongs to Group B, while the secondary 2117F belongs to Group C.

Any unit may contribute to one or more of these failure categories.

1.	Critical Failure Detectable (covered)	Code = CFC
2.	Critical Failure Undetectable (not covered)	Code = CFN
3.	Noncritical Failure Detectable	Code = NCF
4.	Noncritical Failure Undectable	Code = NCF

For reliability analysis purposes, categories 3 and 4 are combined into a single category, NCF, because they do not impact on system reliability.

Whether a failure is critical or non-critical often depends on user's application. What is a critical failure to one application may not be critical to another.

Whether a failure is detectable or not depends on the hardware and software health check features provided by HP as well as additional features that might be provided by the user.

The CFC, CFN and NCF values shown in Appendix C are based on engineering judgement of Systemsafe/1000 health check capabilities when used with a specific application program.

b. After the coverage factors have been assigned, allocate failure rates to the different groups by multiplying the unit failure rate by the applicable coverage factor for each failure category.

1. Allocate failure rates to Groups by CFC Coverage Factor.
2. Allocate failure rates to Groups by CFN Coverage Factor.
3. Establish CFN fail rates for Groups (Xp) and (Xs).
4. Allocate Xs failure rate back into Standby System Group.

No specific action is needed with factors for the NCF column as these are not used in system reliability calculations.

The following example illustrates the usage of this method.

c. Table 1 summarizes the results from these steps. The process is illustrated by the following step-by-step example for Group A CFC Coverage using values from Appendix C.

Unit 1 Calculated Fail Rate (CFR) is 9.80008% per 1000 Hrs. CFC coverage factor is .95. (.95 x 9.80008) = 9.31008 which is the CFC allocation to Group A from Unit 1.

Unit 2 Calculated Fail Rate (CFR) is 17.52848% per 1000 Hrs. CFC coverage is also .95. (.95 x 17.52848 = 16.65206 which is the CFC allocation to Group A from Unit 2.

Since there are no other units in Group A, the two CFC Failure Rates are added and become the Total For Group A in Table 1.

Group A, CFC, = 9.3100B + 16.65206 = 25.96214.

Repeat for Group CFC and CFN coverage on all 21 units.

Table 1. Coverage "Adjusted" Failure Rates & MTBF Values

Rel. Group	Failure Rate In % Per 1000 Hours CFC	CFN	"Adjusted"	Calculated MTBF In Hours
A	25.96214	1.36643	25.96214	3852
B	40.58041	6.97542	40.58041	2464
C	42.95856	7.28998	50.24854	1990
Xp*	—	—	8.34185	11988

* (Xp) = Sum of all CFN values for Primary Groups (A+B).

(Xs) = Sum of all CFN values for Standby Group (C). Xs values are added to Standby Group Failure Rate.

7. REVIEW OF RELIABILITY MATHEMATICS THAT WILL BE USED

In Step (8), basic probability formulas are used to establish an effective calculated failure rate for the redundant system. Since the probability values are based on the Mean-Time-To-Repair (MTTR), the system effective failure rate is invalid unless actual system operating conditions realize the same MTTR. The MTTR value assumed for Systemsafe/1000 is 24 hours. In Step 9, the system failure rate is used to establish System HRPCT Integration Factors which are then used to develop System Reliability Information.

Additional information on HRPCT can be obtained from HP DSD Quality and Reliability Engineering. Request Reliability Application Note RMP-002.

a. Basic Probability & Availability Terms and Formulas

1. Terms:

Pf = Probability of failing a given time interval
Ps = Probability of surviving the time interval
Ps + Pf = 1 (Ps = 1-Pf) (Pf = 1-Ps)
A = Fraction of real time that system is available

2. Formulas:

$Ps = e^{-t/M}$
t = MTTR (Probability Interval)
M = MTBF in hours
e = Natural Log Base

$$M = \frac{-t}{\mathrm{Log}_n\ Ps}$$

$$A = \frac{MTBF}{MTBF + MTTR} \quad (\times 100 \text{ for } \%)$$

b. Probability Formulas For Redundant Units

Probability of Survival of all units in a series

Ps = (Ps1 x Ps2 x Ps3.... x PsN)

Probability of Survival for one of two parallel units

Ps = 1-(Pf1 x Pf2)

Probability of Survival for series/parallel combinations

Ps = Ps x (1-(Pf1 x Pf2)) x Ps x
(1-(Pf3 x Pf5)) x Psp .. etc

Each parallel group is reduced to an equivalent series Ps and combined with other units in the series.

Appendix D presents an introduction to the Hazard Rate Power Curve Technology (HRPCT) and outlines some formulas that will be applied. Review Appendix D before proceeding with the next steps.

From this point on, familiarity with HRPCT and simple probability and availability mathematics is presumed.

8. CALCULATE BASIC FAILURE RATE/MTBF FOR A REDUNDANT SYSTEM

The format in Table 2 is convenient for completing and recording the results of the mathematical steps involved in arriving at redundant system HRPCT factors. System Level HRPCT Factors are shown in the table. How they are established is covered in Step 9.

Table 2. System HRPCT Factor Calculations (Appendix C Coverage)

GROUP CVG ADJUSTED VALUES			
FAILURE RATE %/K HRS		MTBF	RELIABILITY MODEL 24 HOUR PROBABILITIES
A	25.96214	3852	Ps AA = .999,961,422
B	40.58041	4264	Ps BC = .999,883,802
C	50.24854	1990	
Xp	8.34185	11988	Ps Xp = .998,000,001

HRPCT INTEGRATION FACTORS	SYSTEM MTBF AND FAILURE RATE
A = $-.666590 \times 10^{-3}$	Ps = .997,845,539
B = .657103	Pf = .002,154,461
Ts = 10 Hrs	MTBF = 11,128 Hrs

Effective Failure Rate = 8.98634 %/K HRS

9. ESTABLISH SYSTEM HRPCT INTEGRATION FACTORS

The HRPCT "A" Factor is directly proportional to product or system complexity as reflected by the Effective Calculated Failure Rate.

Table 3 provides conversion factors "Ap" to be used with the Effective Failure Rate to derive an "A" Value for the system.

Multiplying Effective Failure Rate by the desired "Ap" Value gives the system "A" Value. The specific "Ap" values in Table 3 apply only with calculated failure rates based on RADC-II methods as implemented by HP Data Systems Division. Do not use them with failure rates calculated by other methods.

"Ap" Values in Table 3 are derived from field failure data and the RADC-II Calculated Failure Rates on a variety of products. The values shown are based on the Standard Normal Distribution. The higher "Ap" values generate a lower level of reliability prediction.

Values in Table 3 are for lower limits. For example, 80% "Ap" values will predict a reliability level that will be exceeded by 80 percent of the systems.

Values used for examples in this application note will be exceeded by 50% of the systems.

Table 3. HRPCT "Ap" Factors Per Desired Lower Confidence Limit

DESIRED LCL	"Ap"/1% K Hrs CALC FAIL RATE	** MEAN VALUE = $-.741760 \times 10^{-4}$ STD DEVIATION = $.080653 \times 10^{-4}$
90%	$-.844973 \times 10^{-4}$	** The Mean Value (LCL = 50%) is used for examples in this Reliability Application Note.
80%	$-.809493 \times 10^{-4}$	
70%	$-.784497 \times 10^{-4}$	
60%	$-.762725 \times 10^{-4}$	
50%	$-.741760 \times 10^{-4}$ **	

NOTE: "Ap" and "A" values are valid only for "B" of .657103
HR Curve Initialization Time is 10 Hours = Ts.

10. CALCULATION OF DESIRED SYSTEM HARDWARE RELIABILITY INFORMATION

It is assumed that Appendix D has been read and that HRPCT formulas involved in calculating reliability information are understood.

The HRPCT reliability information format that has proven to be of most value is used for Appendix E. It shows failures by month for 100 products or systems over the first 36 months of operation with the desired power-on usage rate per month. The rate for Appendix E is 730 hours. Appendices E-1 thru E-3 serve to show the leverage the coverage factor has on the reliability of redundant systems.

E-1 Is for the Systemsafe basic function without redundancy or switching. It treats Groups A and B as one system using the same "Ap" factor from Table 3 to scale "A" directly from the calculated failure rate. Detailed calculations (per Table 2 Format) are not shown.

E-2 Uses the Systemsafe coverage per Appendix C which has been the reference for all examples in this note.

E-3 Demonstrates the result of making a conventional assumption of 100 percent coverage. In this model, groups A and B are treated as fully redundant; Switching Power and Control is a series group, and groups Xp or Xs do not exist. Detailed calculations are not shown.

Table 4 in Appendix E provides expected failures and Average MTBF for a population of 100 systems. Values are by month and cumulative for months 1 thru 36.

Failures divided by 100 gives probability of failure for the time interval to which the failures apply.

Table 4. Reliability Comparisons: Redundancy and Coverage

RELIABILITY PARAMETER OF INTEREST	VALUES IN HOURS: (25 YEARS = 219,000 HOURS)		
	APPENDIX E-1 NONREDUNDANT	APPENDIX E-2 SYSTEMSAFE/1000	APPENDIX E-3 100% COVERAGE
Average MTBF First 3 Years	6,016	49,428	121,613
TIME TO FAILURE			
1st	2,870	68,478	268,785
2nd	8,089	196,186	771,109
3rd	14,899	363,342	1,428,768
4th	23,011	562,711	
5th	32,256		
Availability Using Time to 1st Failure and 24 hr MTTR			
	99.17%	99.96%	99.99%

Appendix A
RADC-II Calculated Failure Rates by Product

Disc and Controller (Group A) — **MTBF = 3659 Hrs**

13037C	Controller	9.80008
7920A	Disc	17.52848
		27.32856

System Console (Group B and C) — **MTBF = 4202 Hrs**

2645A	CRT Terminal +032	16.91189
+007	Dual Cartridge Tape	6.88895
		23.80084

System Processor (Group B and C) — **MTBF = 1943 Hrs**

12966A	Console Interface	2.35859
2117F	Base CPU and Power Supply	25.54957
12566C	Microcircuit I/F (HC Status)	1.10573*
12789M	2 MB FC Memory System	8.92408
12791A	Firmware Expansion Module	0.88246
12824A	Vector Instruction Set	0.25704
12897B	Dual Ch. Port Cntrlr.	1.88387
12991B	Power Fail Recovery	3.28480
12992C	Terminal Loader ROM	0.08568
13175B	Magnetic Disc Interface	1.59488
13178C	Dual Disc Interface	2.43000*
29402C	Cabinet and Pwr Distr.	0.34564
93768A	Watchdog Timer	1.42384*
93770A	Clock/TBG/Synch.	1.33625
		51.46243

Switch Power and Control (Group C) — **MTBF = 33773 Hrs**

93550A	Base Chassis and Pwr Supply	1.79308
93550-046	Switch Control Assembly	1.16784
		2.96092*

Output Transfer Switch (Not included in model) — **MTBF = 304146 Hrs**

93550-016	48-Pin Switch	0.32879

** Delete these for nonredundant system*

Appendix B
Hardware Products: Health Check Coverage Worksheet

UNIT	MODEL	PRODUCT DESCRIPTION	FAIL RATE (CFR)	HEALTH CHECK COVERAGE FACTORS (GRC)	(CFC)	(CFN)	(NCF)
1	13037C	Disc Ctlr	9.80008				
2	7920A	Disc	17.52848				
3	13175B	Disc I/F	1.59488				
4	**13178C**	**Disc I/F**	2.43000				
5	2645A	Terminal	16.91189				
6	+ 007	Term Mini-Crtdg	6.88895				
7	**12966A**	**Term I/F**	2.35859				
8	2117F	CPU & Pwr Sply	25.54957				
9	12789M	2 MB FC Mem	8.92408				
10	93770A	Clock/Sync	1.33625				
11	12791A	FEM	0.88246				
12	12824A	VIS	0.25704				
13	12897B	DCPC	1.88387				
14	12991B	Pwr Fail Recovery	3.28480				
15	12992B	Disc Ldr ROM	0.08160				
16	12992C	Term Ldr ROM	0.08568				
17	**29402C**	**Cab/Pwr Dstr**	0.34564				
18	93768A	W DG Timer	1.42384				
19	**12566C**	**WD Tmr I/F**	1.10573				
20	93550A	Sw Case/Pwr	1.79308				
21	Opt 46	Switch Control	1.12453				

Appendix C
Hardware Products: Health Check Systemsafe/1000 Coverage Worksheet

UNIT	MODEL	PRODUCT DESCRIPTION	FAIL RATE (CFR)	(GRC)	HEALTH CHECK COVERAGE FACTORS (CFC)	(CFN)	(NCF)
1	13037C	Disc Ctlr	9.80008	AA	0.95	0.05	0.00
2	7920A	Disc	17.52848	AA	0.95	0.05	0.00
3	13175B	Disc I/F	1.59488	BC	0.90	0.10	0.00
4	**13178C**	**Disc I/F**	2.43000	BC	0.90	0.10	0.00
5	2645A	Terminal	16.91189	BC	0.10	0.10	0.80
6	+ 007	Term Mini-Crtdg	6.88895	BC	0.00	0.00	1.00
7	**12966A**	**Term I/F**	2.35859	BC	0.10	0.10	0.80
8	2117F	CPU & Pwr Sply	25.54957	BC	0.80	0.10	0.10
9	12789M	2 MB FC Mem	8.92408	BC	0.95	0.05	0.00
10	93770A	Clock/Sync	1.33625	BC	0.80	0.10	0.10
11	12791A	FEM	0.88246	BC	0.95	0.05	0.00
12	12824A	VIS	0.25704	BC	0.05	0.95	0.00
13	12897B	DCPC	1.88387	BC	0.95	0.05	0.00
14	12991B	Pwr Fail Recovery	3.28480	BC	0.20	0.00	0.80
15	12992B	Disc Ldr ROM	0.08160	BC	0.00	0.00	1.00
16	12992C	Term Ldr ROM	0.08568	BC	0.00	0.00	1.00
17	**29402C**	**Cab/Pwr Dstr**	0.34564	BC	0.05	0.05	0.00
18	93768A	W DG Timer	1.42384	BC	0.95	0.05	0.00
19	**12566C**	**WD Tmr I/F**	1.10573	BC	0.20	0.80	0.00
20	93550A	Sw Case/Pwr	1.79308	C	0.95	0.05	0.00
21	Opt 46	Switch Control	1.12453	C	0.60	0.20	0.20

Appendix D
Introduction to the Hazard Rate Power Curve Technology

The Hazard Rate Power Curve Technology was developed and proven by DSD beginning in 1974. It accurately models the rate at which the risk of failure diminishes with time as the weaker members of the component population are removed. The parameters are derived from actual failure experience at the product level, however it can be applied at any level (component through system) for which failure data exists.

The typical shape of a Hazard Rate Power Curve is shown below.

Some of the More Useful HRPCT Formulas and their Applications

1. $F = A\ [T1^B - T2^B]$

   Calculates number of failures "F" during the time interval established by T1 and T2 (X, Y, or Z in the figure). All time intervals are defined by T1 and T2 in the formulas.

2. $$MTBF = \frac{(T2 - T1)}{F}$$

   Calculates the Average MTBF realized during the interval. Average Failure Rate during the T1 to T2 interval is:

   $1/MTBF \times 10^5$ For failure rate in percent per 1000 hours.

   $1/MTBF \times 10^9$ For failure rate in "FIT" (1 FIT is equal to one failure per billion operating hours).

3. $$T2 = Log^{-1}\left[\frac{1}{B}\ Log_{10}\left[T1^B - \frac{F}{A}\right]\right]$$

   Calculates "T2" time point for the T1 to T2 interval for any desired fraction failing "F". This formula answers questions such as: "How long before the first failure, the second, third, etc."

4. $H = C\,T^M \times 10^5$

   C & M are Related to A & B

   $C = A \times (-B)$
   $M = B - 1$

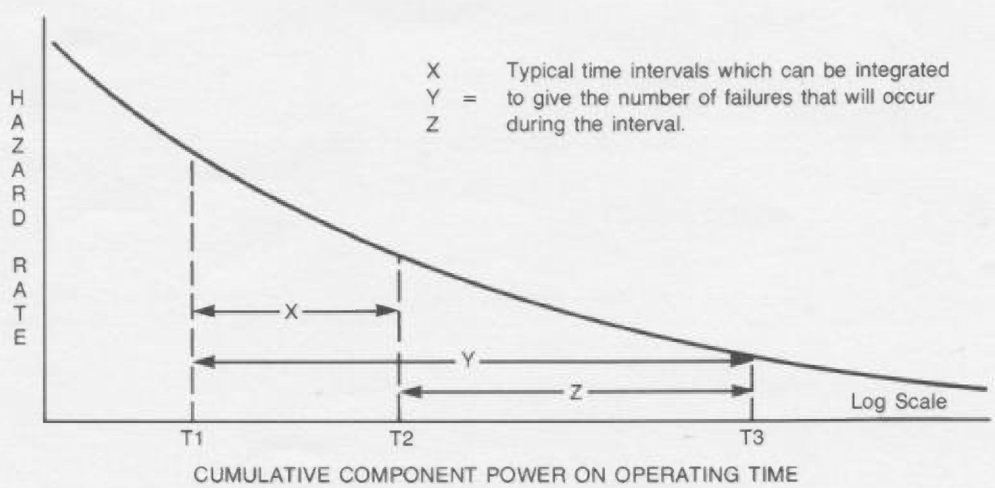
   Calculates Hazard Rate "H" at Time "T". The 10^5 factor gives "H" in failures per 10^5 hours or percent per 1000 hours. 10^9 will give H in FITs or Failures per billion hours.

5. $$A = \frac{F}{T1^B - T2^B}$$

   Calculates the "A" value when B is known and "F" has been established for the time interval T1 to T2. This is a very useful arrangement of Formula (1). "F" is easily established from field failure data.

Definition of Terms

F = Fraction failing during time interval T1 to T2
= Pf or probability of failing during time interval.
Ps = probability of surviving time interval.
Ps = (1−Pf) or (Ps = 1−F)



A = Scale Factor proportional to product complexity. It is derived from actual field failure experience and may be scaled relative to electronic component count or calculated failure rate. Both represent product complexity and relative risk of failure.

B = Power Law Equation Integration Factor. "B" is a function of the rate at which risk of failure diminishes with accumulation of operating time on the component population.

Method for deriving "B" from field failure data is not difficult and is covered in the Reliability Application Note on HRPCT. It is not discussed in this summary.

C = Scale Factor used in Hazard Rate Calculation.

$$C = A \times (-B)$$

M = Power Law Slope Factor used in Hazard Rate Calculation.

$$M = B - 1$$

Ts = Curve Initialization Time. Ts is used in deriving "A" and "B" from actual field failure experience. Ts is typically the power on time accumulated up to the time of factory shipment. Both "A" and "B" are a function of Ts.

T1 = Start time for any interval to be integrated. T1 may be any desired time including Ts and values lower than Ts.

T2 = Defines the ending time for the interval to be integrated.

Note: Ts, T1, and T2 are stated in hours or any fraction of an hour.

Appendix E
Examples of "Field" Reliability Predictions

Hewlett-Packard, Data Systems Quality and Reliability Engineering Field Failure Prediction

The average MTBF observed under field conditions is a function of the product's Hazard Rate Curve and varies with the specific time interval of interest. The Hazard Rate Curve reflects the rate at which the risk of failure diminishes as operating time is accumulated on the product population.

Hazard Rate Curves have been established for the products of Hewlett-Packard, Data Systems Division, and have been verified by billions of component operating hours under field conditions.

The attached Field Failure Prediction shows the average failure levels expected during the first 36 months of operation for 100 units when operated at the indicated hours per month.

If there is an OEM test period, the failure prediction for the test period will reflect an additional multiplier of 1.5 (if the test is at 25°C). Further adjustment will be made for test temperatures greater than 25°C.

If higher test temperatures are used during the test period, the initial T1 time for the first month of field operation will be adjusted to the time point where normal 25°C operation would have resulted in the same total failures expected at the higher test temperature. The OEM test failures are not included in the cumulative totals.

Three simple operating formulas are involved

Curve Integration:	$F = A(T1^B - T2^B)$
To Draw HR Curve:	$H = C(T^M) \times 10^5$
For Period MTBF:	Avg MTBF $= (T1 - T1)/F$

Definition of Terms:

F = Failures Per Unit during integration period (T1 to T2)
A = Base Failure Rate Multiplier
B = Hazard Rate Exponent
T = Time Point (S) in hours
H = Hazard Rate (in % per 1000 hours) at time (T)
C = Base Failure Rate Multiplier for Curve = A × (−B)
M = Hazard Rate Exponent for Curve = B − 1

Note: The attached listing includes the "A" and "B" factors used. These factors and the above formulas may be used to explore other periods of interest. The "C" and "M" factors are derived from "A" and "B" as indicated above.

Appendix E-1: Field Failure Prediction, Systemsafe/1000

SIMPLEX SYSTEM: Functionally Equivalent to SS-1000

Calculation Failure Rate:	73.83142 %/KHrs	Report Length:	36 Mos
OEM Test Multiplier:	1.0	OEM Test Period:	0 Hrs
OEM Test Ambient (C):	25°	Usage Per Month:	730 Hrs
'A'&'B' Factors:	$-.547652 \times 10^{-2}$, .657103	Ship Point:	10 Hrs

Month	T1 Hrs	T2 Hrs	Units	Predicted Failures (F) Monthly	Predicted Failures (F) Cumulative	Average MTBF (Hrs) Monthly	Average MTBF (Hrs) Cumulative
OEM TEST	10	10	100	0.000000			
1	10	740	100	39.574944	39.57	1845	1845
2	740	1470	100	23.971085	63.55	3045	2298
3	1470	2200	100	20.031174	83.58	3644	2620
4	2200	2930	100	17.830933	101.41	4094	2879
5	2930	3660	100	16.353382	117.76	4464	3099
6	3660	4390	100	15.264264	133.03	4782	3293
7	4390	5120	100	14.413404	147.44	5065	3466
8	5120	5850	100	13.723257	161.16	5319	3624
9	5850	6580	100	13.146893	174.31	5553	3769
10	6580	7310	100	12.654627	186.96	5769	3904
11	7310	8040	100	12.228243	199.19	5970	4031
12	8040	8770	100	11.852369	211.04	6159	4151
13	8770	9500	100	11.518709	222.56	6338	4264
14	9500	10230	100	11.218744	233.78	6507	4372
15	10230	10960	100	10.947124	244.73	6668	4474
16	10960	11690	100	10.700039	255.43	6822	4573
17	11690	12420	100	10.472710	265.90	6970	4667
18	12420	13150	100	10.263964	276.17	7112	4758
19	13150	13880	100	10.070192	286.24	7249	4846
20	13880	14610	100	9.890295	296.13	7381	4930
21	14610	15340	100	9.721760	305.85	7509	5012
22	15340	16070	100	9.564991	315.41	7632	5092
23	16070	16800	100	9.416647	324.83	7752	5169
24	16800	17530	100	9.277660	334.11	7868	5244
25	17530	18260	100	9.145761	343.25	7982	5317
26	18260	18990	100	9.021284	352.27	8092	5388
27	18990	19720	100	8.903357	361.18	8199	5457
28	19720	20450	100	8.790644	369.97	8304	5525
29	20450	21180	100	8.683815	378.65	8406	5591
30	21180	21910	100	8.582399	387.23	8506	5655
31	21910	22640	100	8.484129	395.72	8604	5719
32	22640	23370	100	8.390335	404.11	8700	5781
33	23370	24100	100	8.302156	412.41	8793	5841
34	24100	24830	100	8.215315	420.63	8886	5901
35	24830	25560	100	8.132954	428.76	8976	5959
36	25560	26290	100	8.054136	436.81	9064	6016
Total with OEM Test:					436.81		

Appendix E-2: Field Failure Prediction, Systemsafe/1000

DUPLEX SYSTEM: Coverage per Appendix C

Calculation Failure Rate:	8.98661 %/KHrs	Report Length:	36 Mos
OEM Test Multiplier:	1.0	OEM Test Period:	0 Hrs
OEM Test Ambient (C):	25°	Usage Per Month:	730 Hrs
'A'&'B' Factors:	$-.666590 \times 10^{-3}$, .657103	Ship Point:	10 Hrs

Month	T1 Hrs	T2 Hrs	Units	Predicted Failures (F) Monthly	Predicted Failures (F) Cumulative	Average MTBF (Hrs) Monthly	Average MTBF (Hrs) Cumulative
OEM TEST	10	10	100	0.000000			
1	10	740	100	4.816975	4.82	15155	15155
2	740	1470	100	2.917707	7.73	25020	18876
3	1470	2200	100	2.438150	10.17	29941	21528
4	2200	2930	100	2.170341	12.34	33635	23657
5	2930	3660	100	1.990498	14.33	36674	25465
6	3660	4390	100	1.857932	16.19	39291	27051
7	4390	5120	100	1.754368	17.95	41610	28474
8	5120	5850	100	1.670364	19.62	43703	29771
9	5850	6580	100	1.600210	21.22	45619	30966
10	6580	7310	100	1.540293	22.76	47394	32078
11	7310	8040	100	1.488395	24.25	49046	33120
12	8040	8770	100	1.442644	25.69	50602	34102
13	8770	9500	100	1.402032	27.09	52067	35031
14	9500	10230	100	1.365521	28.46	53459	35916
15	10230	10960	100	1.332460	29.79	54786	36760
16	10960	11690	100	1.302385	31.09	56051	37568
17	11690	12420	100	1.274715	32.36	57268	38344
18	12420	13150	100	1.249307	33.61	58432	39091
19	13150	13880	100	1.225721	34.84	59557	39811
20	13880	14610	100	1.203825	36.04	60640	40506
21	14610	15340	100	1.183311	37.23	61691	41180
22	15340	16070	100	1.164230	38.39	62702	41832
23	16070	16800	100	1.146173	39.54	63690	42466
24	16800	17530	100	1.129256	40.67	64644	43082
25	17530	18260	100	1.113202	41.78	65577	43681
26	18260	18990	100	1.098051	42.88	66481	44265
27	18990	19720	100	1.083697	43.96	67362	44834
28	19720	20450	100	1.069978	45.03	68226	45390
29	20450	21180	100	1.056975	46.09	69065	45933
30	21180	21910	100	1.044631	47.13	69881	46464
31	21910	22640	100	1.032669	48.17	70691	46983
32	22640	23370	100	1.021253	49.19	71481	47492
33	23370	24100	100	1.010520	50.20	72240	47990
34	24100	24830	100	.999950	51.20	73004	48479
35	24830	25560	100	.989925	52.19	73743	48958
36	25560	26290	100	.980332	53.17	74465	49428
Total with OEM Test:					53.17		

Appendix E-3: Field Failure Prediction, Systemsafe/1000

DUPLEX SYSTEM: Conventional 100% Coverage

Calculation Failure Rate:	3.65251 %/KHrs	Report Length:	36 Mos
OEM Test Multiplier:	1.0	OEM Test Period:	0 Hrs
OEM Test Ambient (C):	25°	Usage Per Month:	730 Hrs
'A'&'B' Factors:	$-.270929\times10^{-3}$,.657103	Ship Point:	10 Hrs

Month	T1 Hrs	T2 Hrs	Units	Predicted Failures (F) Monthly	Predicted Failures (F) Cumulative	Average MTBF (Hrs) Monthly	Average MTBF (Hrs) Cumulative
OEM TEST	10	10	100	0.000000			
1	10	740	100	1.957813	1.96	37287	37287
2	740	1470	100	1.185874	3.14	61558	46442
3	1470	2200	100	.990962	4.13	73666	52967
4	2200	2930	100	.882114	5.02	82756	58205
5	2930	3660	100	.809018	5.83	90233	62653
6	3660	4390	100	.755139	6.58	96671	66556
7	4390	5120	100	.713046	7.29	102378	70058
8	5120	5850	100	.678903	7.97	107526	73248
9	5850	6580	100	.650390	8.62	112240	76189
10	6580	7310	100	.626037	9.25	116606	78925
11	7310	8040	100	.604944	9.85	120672	81488
12	8040	8770	100	.586349	10.44	124499	83903
13	8770	9500	100	.569842	11.01	128106	86191
14	9500	10230	100	.555003	11.57	131531	88367
15	10230	10960	100	.541565	12.11	134794	90444
16	10960	11690	100	.529342	12.64	137907	92432
17	11690	12420	100	.518095	13.15	140901	94341
18	12420	13150	100	.507769	13.66	143766	96178
19	13150	13880	100	.498183	14.16	146533	97949
20	13880	14610	100	.489283	14.65	149198	99661
21	14610	15340	100	.480945	15.13	151784	101318
22	15340	16070	100	.473190	15.60	154272	102924
23	16070	16800	100	.465851	16.07	156702	104483
24	16800	17530	100	.458975	16.53	159050	105998
25	17530	18260	100	.452450	16.98	161344	107473
26	18260	18990	100	.446292	17.43	163570	108909
27	18990	19720	100	.440458	17.87	165737	110310
28	19720	20450	100	.434882	18.30	167862	111677
29	20450	21180	100	.429597	18.73	169927	113013
30	21180	21910	100	.424580	19.16	171935	114319
31	21910	22640	100	.419718	19.58	173926	115597
32	22640	23370	100	.415078	19.99	175870	116849
33	23370	24100	100	.410716	20.40	177738	118074
34	24100	24830	100	.406420	20.81	179617	119276
35	24830	25560	100	.402345	21.21	181436	120455
36	25560	26290	100	.398446	21.61	183212	121613
Total with OEM Test:					21.61		

Appendix F
Alternate Method for Modeling Coverage

Coverage for Specific Applications (Used in this Application Note)

The method for establishing coverage used in this note presumes that understanding of assembly functions, health check subsystem approach, and the requirements of a specific application will permit technical allocation of calculated failure rates to three failure level codes (CFC, CFN, and NCF). The CFC Group is assumed to be 100% covered and the CFN Group to have no coverage. Within the system function, CFN assemblies impact on reliability in the same way as any other series group in the system. The NCF Group is set aside and is not a factor in the reliability calculations.

This method allows good flexibility for assuring that a reliability logic model represents the reliability considerations for a specific application.

Coverage for General Purpose or Multiple Applications (This Appendix)

When the application is non specific, it becomes more difficult to determine an accurate coverage factor and considerable judgement must be used. The following formula distributes the risk of failing to detect a failure throughout all circuitry in a unit. The results may be slightly more pessimistic which, is appropriate for general purpose or multiple applications.

DISTRIBUTED COVERAGE FORMULA

Pss = Ps + C(Pr−Ps)

Pss = Coverage Adjusted Ps for a subsystem consisting of a pair of redundant units.

C = Coverage Factor: (Fraction between 0 and 1)

Pr = 1− (Pf x Pf)

Pr = Ps for one of two units with 100% coverage: Pf = Probability of failure for one unit.

Ps = Ps for one unit in a nonredundant mode.

The Coverage Factor may be determined by any method that will provide the desired confidence in the factor selected.

USING HRPCT WITH THIS METHOD

Once the Effective Failure Rate for the system has been calculated, the System HRPCT Integration Factors ("A" and "B") are calculated from the "Ap" Factors in Table 3. All other HRPCT methods and formulas apply, once "A" and "B" are established for the system.

Example Using Distributed Coverage Formula

This example assumes that coverage is equivalent to that for Appendix C as listed in Table 1. Regardless of the method used to evaluate coverage, the units which can fail and not impact on system reliability must be left out of the model. Failure to do this will distort the true value of redundancy.

In adapting the information from Table 1 to this model, the sum of CFC and CFN failure rates will equal the 100% reference and the CFC fraction of this will determine the coverage factor.

Table 5. Reliability Information Based on RADC-II Failure Rates From Table 1

GROUP	CFC =	CFC+CFN =	COVERAGE	MTBF =
A	25.96214	27.32857	C = .95	3659 Hrs.
B	40.58041	47.55583	C = .85	2103 Hrs.
I/O SW	0.00000	2.96092	C = .00	33773 Hrs.

		24 HOUR PROBABILITY VALUES		
GROUP	UNIT MTBF	Ps =	Pr =	Pss =
AA	3659 Hrs.	.993,462,295	.999,957,258	.999,632,510
BB	2103 Hrs.	.988,652,605	.999,871,237	.998,188,442
S	33773 Hrs.	.999,289,626	.999,999,495	.999,289,626

HRPCT INTEGRATION FACTORS	SYSTEM MTBF AND FAILURE RATE
$A = -.893579 \times 10^{-3}$ B = .657103 Ts = 10 Hrs.	Ps = .997,112,791 PF = .002,887,209 MTBF = 8301 Hours Effective Failure Rate = 12.04674 %/KHrs.

Reliability Comparisons: Specific vs Distributed Coverage

Reliability Parameter of Interest	Values in Hours (25 Years = 219,000 Hours)		
	Systemsafe 1000 Reliability		Conventional 100% Coverage
	Specific CVG	Distributed CVG	
Average MTBF First 3 Years	49,428	38,600	121,613
Time To Failure			
1st	68,478	47,064	268,785
2nd	196,186	134,749	771,109
3rd	363,342	249,506	1,428,768
4th	562,711	386,370	

HEWLETT PACKARD

For more information call the HP Sales Office listed in the White Pages. Or write or phone Hewlett-Packard, Data Systems Division, 11000 Wolfe Rd., Cupertino, CA 95014, (408) 257-7000.

Printed in U.S.A. 12/82
5953-8715