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PLAN FOR THE RELIABILITY AND MAINTAINABILITY EVALUATION OF THE --ETC(U)
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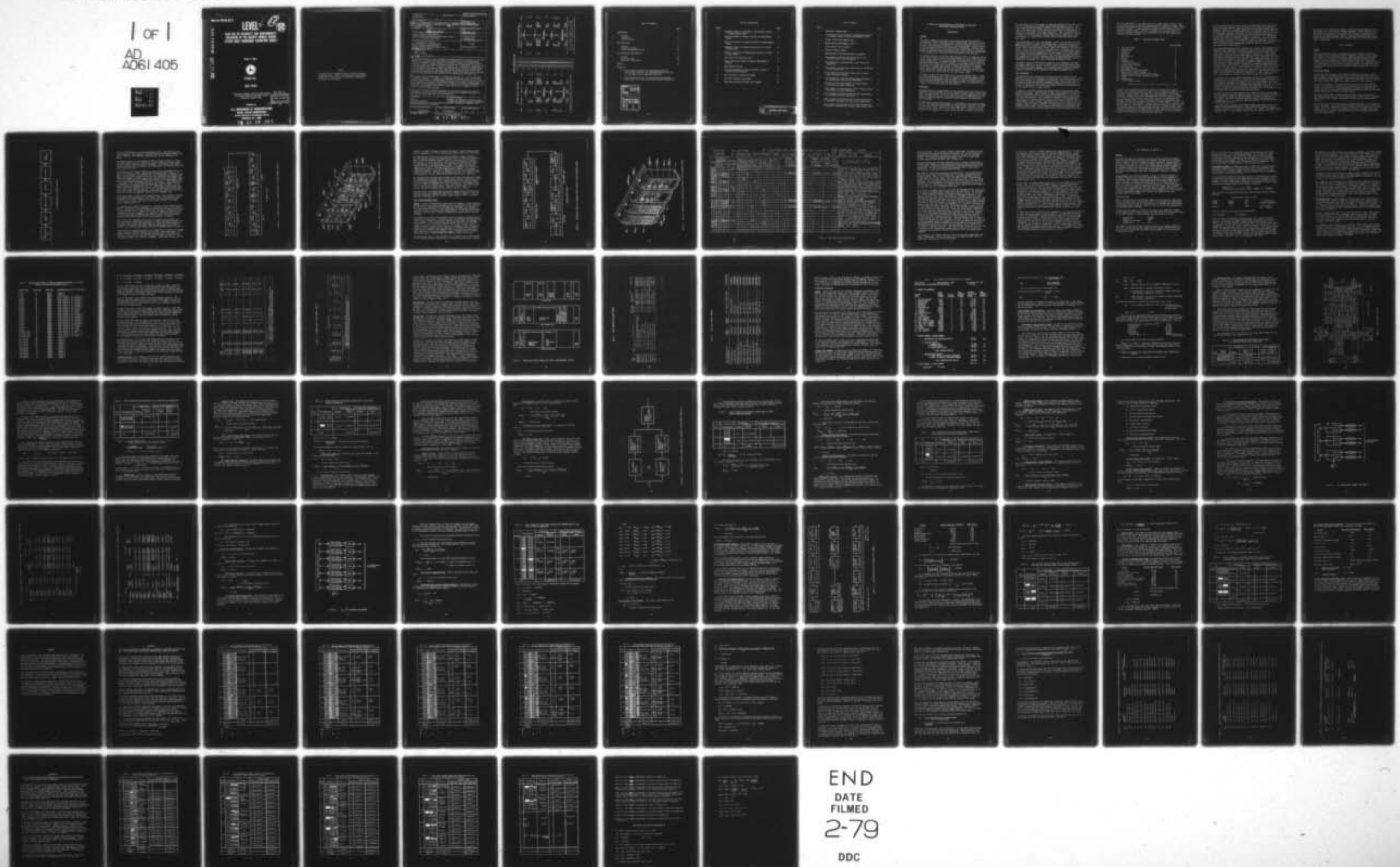

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PLAN FOR THE RELIABILITY AND MAINTAINABILITY EVALUATION OF THE DISCRETE ADDRESS BEACON SYSTEM (DABS) ENGINEERING LABORATORY MODELS

Arthur R. Moss

OCTOBER 1978

NAFEC REPORT

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16. Abstract

The primary objective of the reliability and maintainability evaluation of the DABS sensors is to ascertain any weak points or problem areas in the system design. These are evidenced by the occurrence of distinct or repetitive hardware failure patterns, as well as unusual difficulties encountered in diagnosing, isolating, and correcting these failures. A secondary objective is to obtain mean-time-between-failures (MTBF), mean downtime (MDT), and 90th percentile values of maximum corrective maintenance times for both the single-channel sensors being delivered and a theoretically constructed dual-channel sensor. These values would then be compared with the corresponding values specified in the engineering requirement (ER).

Each sensor will be broken down for reliability purposes into over 200 individual reliability elements. A complete and comprehensive running account of the operational status, failure, and maintenance history of each of these reliability elements will be provided, by use of the Automated Reliability Assessment Program (ARAP), to be operated on the Honeywell computer. By further use of automated techniques, the MTBF, MDT, and maximum corrective maintenance times will be computed for both single- and dual-channel sensors.

This paper provides a detailed description of the data collection and analysis procedures to be used in this evaluation, including the automated techniques and mathematical models employed in the analysis.

17. Key Words
DABS
Air Traffic Control
Equipment Reliability and Maintainability
Automated Reliability Assessment

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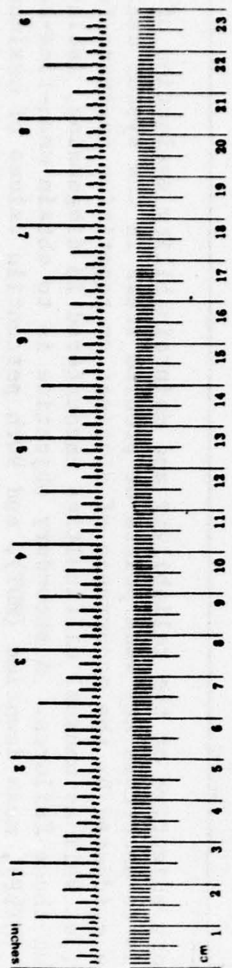
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

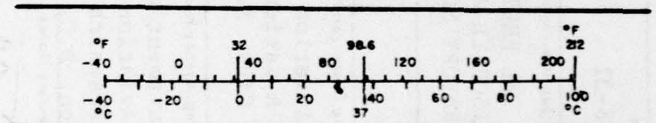
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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RELIABILITY AND MAINTAINABILITY EVALUATION FOR THE DABS ENGINEERING LABORATORY MODELS

INTRODUCTION

PURPOSE.

The primary purpose or objective of the reliability and maintainability evaluation of the Discrete Address Beacon System (DABS) sensors is to ascertain any weak points or problem areas in the system design. These are evidenced by the occurrence of distinct or repetitive hardware failure patterns, as well as unusual difficulties encountered in diagnosing, isolating, and correcting these failures. By identifying such problem areas in the developmental or engineering laboratory models, they can be taken into consideration in the preparation of the production specifications to be developed.

A secondary objective is to obtain some figures of merit or numerical indexes of the overall system reliability and maintainability of the DABS sensor, and compare these figures to the corresponding values specified in the engineering requirement (ER). The figure of merit for reliability is the mean time between failures (MTBF), which is defined as the average length of time that the system can be expected to operate without experiencing a functional failure due to hardware malfunction. A functional failure is a hardware failure which causes either the complete or a partial loss of system functional capability. The ER specifies the MTBF as 1,000 hours for the single-channel sensor and 20,000 hours for the dual-channel sensor.

The figure of merit for maintainability is the mean downtime (MDT), or mean corrective maintenance time. This is defined as the average length of time that corrective maintenance effort is applied to correct a hardware failure. The ER specifies the MDT as 1 hour for both the single- and dual-channel sensors. The ER further specifies the maximum corrective maintenance time as 2 hours at the 90th percentile for both sensors.

BACKGROUND.

The DABS concept is an improvement over the presently used Air Traffic Control Radar Beacon System (ATCRBS) in that it provides a higher quality surveillance capability and accuracy, as well as providing a two-way communications or data link. The DABS concept will also be able to provide a ground-based conflict resolution service called the Automatic Traffic Advisory and Resolution Service (ATARS).

The DABS employs ground-based sensors, or interrogators, and airborne transponders. The DABS has been designed as an evolutionary replacement for ATCRBS to provide the enhanced surveillance and communications capability required for air traffic control (ATC) in the 1980's and 1990's. Compatibility with ATCRBS has been emphasized to permit an extended and economical transition.

The requirement for the development of DABS was identified in the 1969 Department of Transportation Air Traffic Control Advisory Committee study. The first phase of DABS development consisted of a feasibility study and validation of the DABS concept. This study was conducted by the Massachusetts Institute of Technology (MIT) Lincoln Laboratory. After successfully demonstrating the feasibility of the DABS concept, ER's were prepared by Lincoln Laboratory for the development of three single-channel DABS sensors which could operate as a network and interface with en route and terminal ATC facilities.

Texas Instruments, Inc. (TI), was awarded a contract to fabricate the three engineering laboratory models of the DABS sensor. These are currently being fabricated at the TI plant in Plano, Texas, for installation at National Aviation Facilities Experimental Center (NAFEC) and Clementon and Elwood, New Jersey. After completing factory acceptance tests, the sensors will be delivered to the three sites, installed, and subjected to field readiness tests. All of this will be the responsibility of the contractor (TI), with NAFEC and other Federal Aviation Administration (FAA) personnel providing assistance. Upon completion of the field readiness tests, the NAFEC performance tests will be performed on the sensors. The reliability and maintainability evaluation described in this paper is a part of the NAFEC performance tests.

The general purpose of the factory acceptance, field readiness, and NAFEC performance tests is to verify the extent to which the DABS functions comply with those specified in the ER. It is intended that those ER requirements which are successfully demonstrated during the factory acceptance or field readiness tests need not be repeated in the NAFEC performance tests.

TEST PHILOSOPHY.

The objectives of the reliability and maintainability evaluation can be achieved by a study of the hardware failures that occur during normal everyday use of the sensor; i.e., whenever it is energized. Hence, it will not be necessary to perform any special reliability tests, since failure data will be obtained during the time that the NAFEC performance tests are being conducted. If additional failure data are needed, this can be obtained during any subsequent testing or usage periods.

In addition to the MTBF and mean and maximum corrective maintenance times mentioned previously, the ER contains several other reliability and maintainability requirements. These include recovery requirements for the sensors following power restoration after external power interrupts (3.9.4.1.d and 3.9.4.2.d of ER-240-26). Also included are automatic recovery requirements after failure of redundant units (3.9.4.1.e and 3.9.4.2.e of ER-240-26). Demonstration of these recovery requirements would require specific scenarios in which power interrupts and hardware failures would be introduced into the equipment, time to recovery observed, and condition of the files and various software features noted. These recovery test procedures are therefore discussed under the Failure/Recovery Mode Section of the Performance Test Plan.

The three DABS sensors to be delivered will be single-channel sensors. These can be broken down for reliability purposes into 20 reliability element types, comprising approximately 200 individual reliability elements per sensor. These are shown in table 1. These reliability elements vary in complexity from a complete equipment subunit, such as a transmitter or processor, down to a portion of a single printed circuit board (PCB), such as the communications interface PCB-serial element.

TABLE 1. RELIABILITY ELEMENT TYPES

		No. in Sensor
1.	Air-Conditioners	2
2.	Antenna Group	1
3.	Transmitter	1
4.	Receiver	1
5.	Processor	1
6.	WWVB Receiver	1
7.	Tilines	11
8.	Couplers	42
9.	Interface PCB's	5
10.	+5-Volt Power Supplies	36
11.	+12-Volt Power Supplies	4
12.	DABS Computers	35
13.	176k Memory Modules	6
14.	Memory Monitor Switching Element	3
15.	Memory Monitor Serial Element	3
16.	Communications Interface PCB-Serial Element	14
17.	Communications Interface PCB-Channel Element	28
18.	Modems	18
19.	Link Switches	2
20.	Primary Radar Interface	1
	Total--	215

A complete and comprehensive running account of the operational status, failure, and maintenance history of each of these reliability elements will be provided by a data processing system known as the Automated Reliability Assessment Program (ARAP). The ARAP, which was developed in 1971 by NAFEC, (Report No. FAA-RD-74-16 entitled "Automated Reliability Assessment Program" by J. Wojciech (Wojciechowicz), April 1974), is a set of procedures and computer programs used to reduce and analyze failure and maintenance data. The ARAP was originally designed to be run on the 7090 computer. In 1977, the 7090 was replaced by a Honeywell computer with provisions for accessibility by remote terminals. Consequently, the ARAP has been converted for operation on the Honeywell computer. This continuous history of over 200 elements, made available through use of the ARAP, should not only enhance the recognition of distinct or repetitive failure patterns but should also outline any unusual difficulties encountered in repairing these failures.

Not every hardware failure that occurs in the DABS sensor will cause degradation of system function. This is because, even in the single-channel sensors which will be evaluated, several of the subsystems contain redundant elements. Should one of these elements fail, its function will be taken over by a dedicated redundant counterpart, and the system will experience no loss of functional capability. Such failures can be effectively converted into an equivalent number of functional failures through the use of mathematical models which take these redundant elements into account. With all hardware failures thus converted into an equivalent number of functional failures, these mathematical models can be used to compute the effective system MTBF and MDT of both the actual single-channel sensor as well as a theoretically constructed dual-channel sensor.

The mathematical models will be programed for electronic data processing. The inputs to these mathematical models will consist of the total uptimes, total downtimes, and total number of actual hardware failures that have occurred over a given time interval for each of the 20 reliability element types. These will be obtained from the ARAP summary printouts and, after suitable screening to eliminate statistically inordinate values (outliers), the corrected data will be applied to the computer. The mathematical models will not only take into account the presence of redundant elements but will also take into account the manner in which such redundant elements are repaired when failure occurs. Some redundant elements will be repaired immediately upon failure; others will be left in the system until some convenient time occurs in which to effect repairs. Under worst-case conditions, this would be the next 30-day scheduled maintenance period (720 hours) for the single-channel sensor. The program will also have the capability of varying this worst-case time from 720 hours to any desired interval (i.e., 1 day, 1 week, 10 days, etc.) to determine the effect of such variation upon the system MTBF.

In addition to the three sensors themselves, reliability and maintainability evaluations will be performed on certain associated equipment, which will be delivered by TI and used in conjunction with the three sensors. This associated equipment includes the following: the front-end processor (FEP), the system test console (STC), the program support equipment (PSE), and the modems located at the ATC facilities with which the DABS sensors interface. A separate reliability and maintainability evaluation will be performed for each of the above four categories of associated equipment.

The FEP will interface the communications inputs and output from the DABS sensor at NAFEC to the 9020 computer there. The STC, also located at NAFEC, will monitor all sensor-to-sensor interfaces and sensor-to-ATC-facilities interfaces. The PSE is an offline computer facility including memory, peripherals, etc. It is used for compiling programs, quick-look analysis of recorded DABS data, etc.

These associated equipments include many element types which are also contained in the sensors themselves. These include DABS computers, global memories, Tilines (a TI term for an interface bus), modems, and communications interface PCB's. These element types will not be combined with those of the

DABS sensor in the mathematical models for MTBF and MDT determination, since this applies only to the sensor elements themselves. The reliability and maintainability evaluations for the FEP, STC, PSE, and ATC modems will show the failure and maintenance information on the elements comprising each respective equipment grouping. However, statistical comparison may be made between element types in these four categories and the corresponding element types in the sensor.

DATA COLLECTION

GENERAL.

Data collection will consist of logging any event or situation which is different from the normal energized and operational status of the equipment. Such events include: equipment shutdown, scheduled maintenance (when equipment shutdown is involved), hardware failures, engineering changes, and changes in system configuration. These events will be coded onto punched cards which will be associated with the specific reliability elements to which the events pertain. These cards will then be applied to the ARAP system for processing and consolidation of the element failure, maintenance, and status histories.

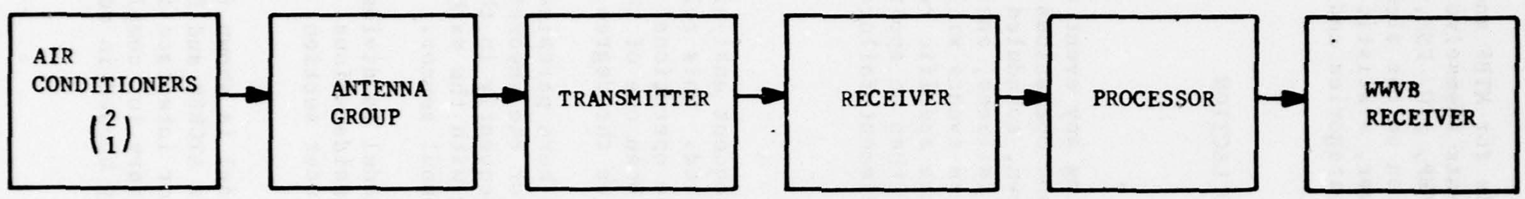
RELIABILITY MODELS.

To facilitate the collection and subsequent analysis of the data, a reliability model of the DABS sensor is used. This reliability model depicts the major equipment subunits which must be operational to achieve full and complete system functional capability. When one of these major subunits involves redundant elements, the model indicates the degree of such redundancy.

The reliability model to be discussed here pertains to the single-channel sensors to be delivered. The model for the theoretically constructed dual-channel sensor will be discussed subsequently in the Data Processing and Analysis section of this paper, along with the mathematical model for the MTBF and MDT determination of the dual-channel sensor.

The single-channel DABS reliability model is divided into three sections based upon physical and functional considerations. These are the interrogator and processor (I&P) section, the computer section, and the communications section.

The I&P section of the reliability model is shown in figure 1. Note the block marked "Processor." This includes the ATCRBS and DABS processors, modulation control unit (MCU), performance monitor interface for the processors, and other support logic, all of which are necessary for complete equipment functional capability. All of this is physically housed in one equipment drawer known as the processor drawer.



1. INTERROGATOR AND PROCESSOR SECTION

FIGURE 1. RELIABILITY MODEL OF INTERROGATOR AND PROCESSOR SECTION OF SINGLE-CHANNEL SENSOR

Note the $\binom{2}{1}$ symbology in the air-conditioners block. This symbology indicates redundancy. Two identical air-conditioners are provided; however, only one is required. This redundancy symbology will be used throughout the model.

The computer section of the reliability model is shown in figure 2. Physically,the computer section is housed in a group of adjacent equipment racks, of which figure 3 shows an artist's conception. Functionally, the computer section is divided into four groups; the ATCRBS group, the ensemble group, and global memories A and B.

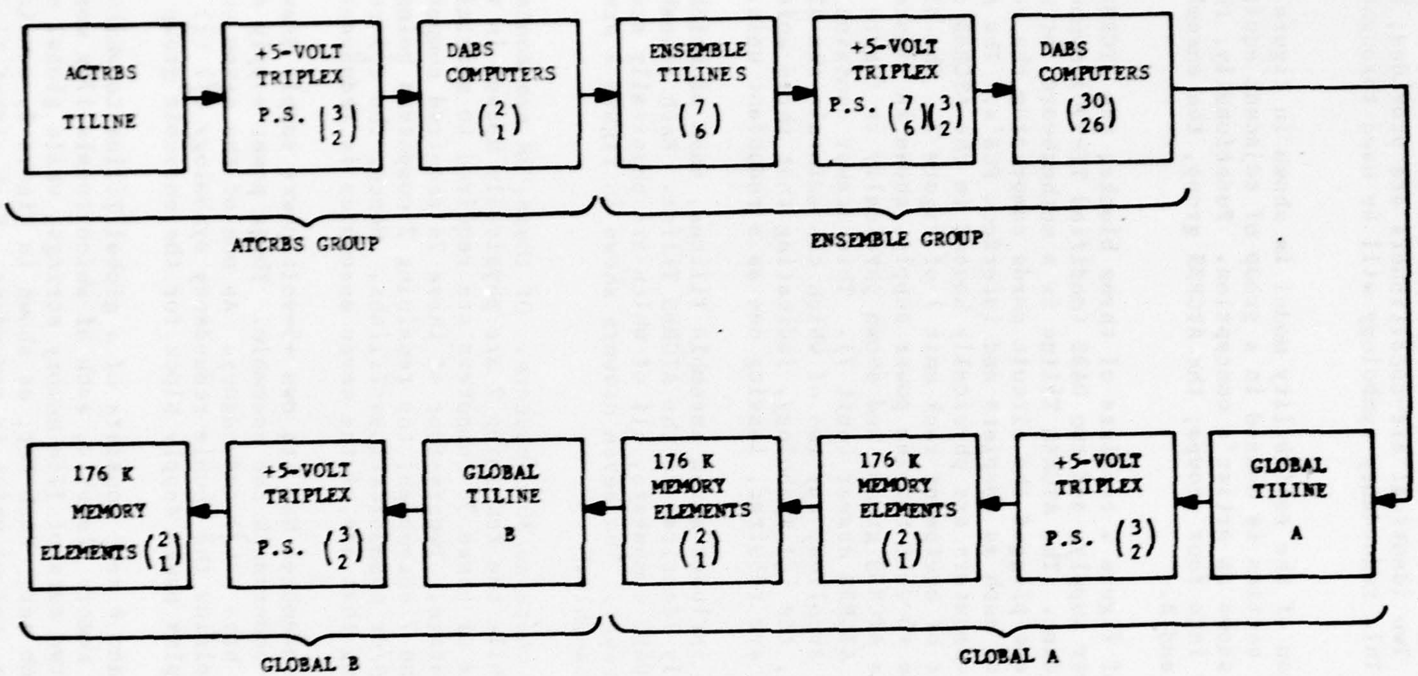
The ATCRBS group of figure 2 consists of three blocks; the ATCRBS Tiline, the 5-volt triplex power supply, and two DABS (modified TI-990) computers, of which one is redundant. The ATCRBS Tiline is a motherboard, or master circuit board, into which are plugged the circuit cards comprising the computers and associated elements, such as couplers and interface PCB's. The ATCRBS Tiline with its two DABS computers are physically housed in the ATCRBS drawer, shown as the upper drawer of equipment rack unit 7 of figure 3. The ATCRBS drawer is energized by the +5-volt triplex power supply, shown in figure 2 as the second block in the ATCRBS group, and shown physically in figure 3 as the drawer beneath the ATCRBS drawer (unit 7). This drawer contains three identical 5-volt power supplies, any two of which can maintain the ATCRBS drawer operational; hence, the $\binom{3}{2}$ symbology, indicating that three units are available, two of which are required, leaving one as a redundant unit.

The ensemble group includes seven ensemble Tilines, each of which is a motherboard and physically identical to the ATCRBS Tiline. Each ensemble Tiline accommodates four DABS computers, all of which are physically accommodated in one equipment drawer. The seven drawers shown in figure 3 are each marked "Computer Ensemble."

The ensemble group contains 30 computers. Of these, 28 are contained in the 7 ensemble Tilines while the remaining 2 are physically housed in the ATCRBS Tiline. Twenty-six of these 30 computers are required to maintain the system in an operational state. Twenty-four of these 26 required computers can be provided by 6 of the 7 ensembles; the remaining 2 computers being available from the ATCRBS and/or communications Tilines. Hence, the $\binom{7}{6}$ redundancy symbology indicating that one of the seven ensembles is redundant.

Each of the seven ensembles has its own +5-volt power supply drawer, also shown in figure 3, underneath the ensemble. These power supply drawers, like the ATCRBS drawer, have a $\binom{3}{2}$ redundancy. As one of the seven ensembles is redundant, this explains the double redundancy symbology $\binom{7}{6}$ $\binom{3}{2}$ shown in in the +5-volt triplex power supply block for the ensemble group of figure 2.

Global memories A and B each consists of a global Tiline to which are attached several strings of memory elements, each of which totals 176k words. Global memory A contains two sets of 176k memory strings, while global memory B consists of one such set. Each set, as shown in figure 2, consists of two 176k memory strings, one of which is redundant. Each global Tiline, with its



2. COMPUTER SECTION

FIGURE 2. RELIABILITY MODEL OF COMPUTER SECTION OF SINGLE-CHANNEL SENSOR

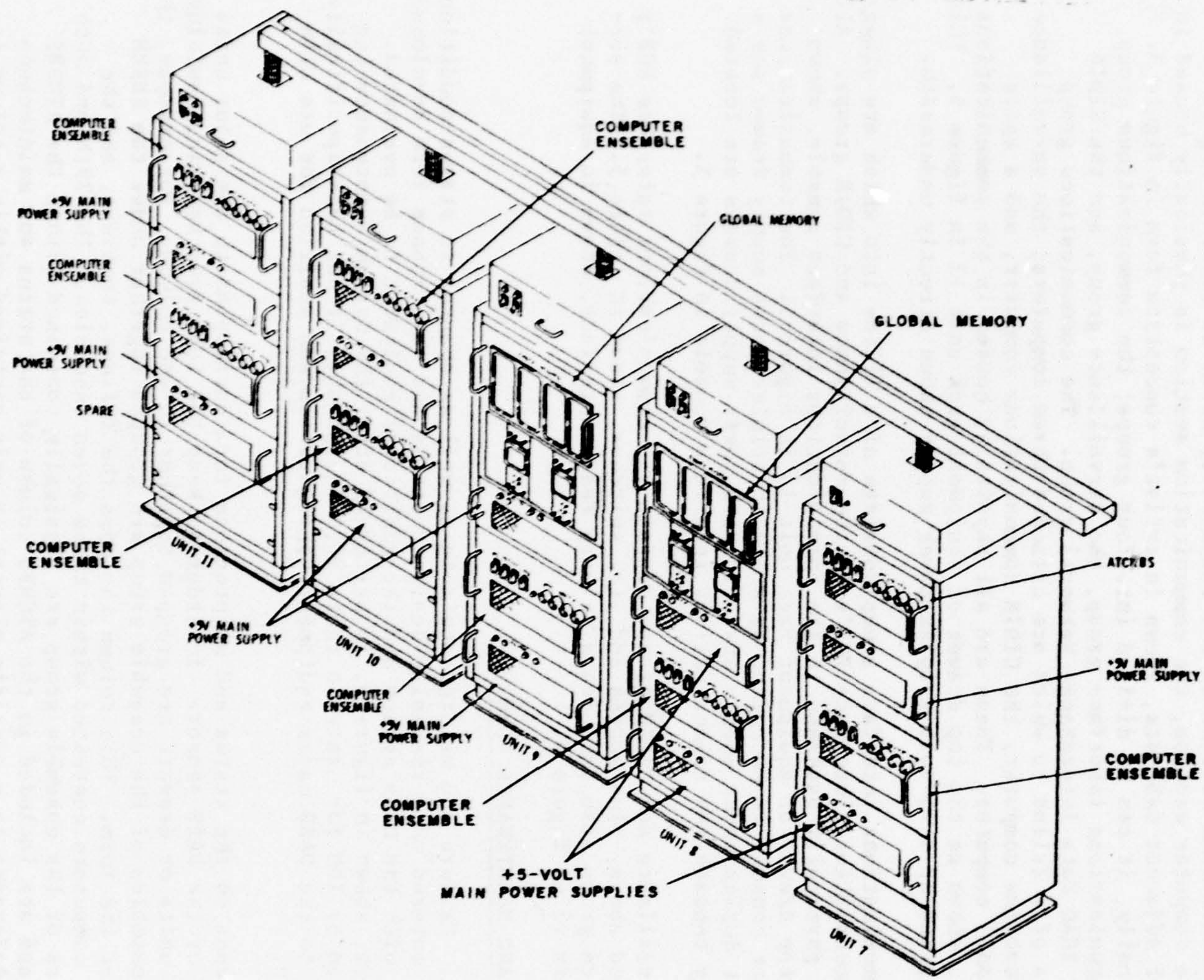


FIGURE 3. ARTIST'S CONCEPTION OF COMPUTER SECTION OF SINGLE-CHANNEL SENSOR

attached 176k memory strings, is physically housed in a global memory drawer, which is energized by a +5-volt triplex power supply located just underneath.

The communications section of the reliability model is shown in figure 4. Like the computer section, the communication section is physically housed in a group of adjacent cabinets, shown in artist's conception form in figure 5. Functionally, it can be divided into four groups; the communications group, the communications interface group, the surveillance group, and the CIDIN (Common ICAO Data Interchange Network) group. The communications group consists of a Tiline to which are attached three computers; the surveillance communications computer, the CIDIN communications computer, and a spare (redundant) computer. These are all physically housed in the communications console, shown as the top drawer of equipment rack unit 12 in figure 5. This is energized by a +5-volt triplex power supply shown directly underneath.

The communications interface group consists of a Tiline into which are plugged the communications interface PCB's of the surveillance and CIDIN groups. All this is physically packaged in the communications interface console, shown as the top drawer of equipment rack unit 13 in figure 5. The communications interface console is energized by a 5-volt triplex power supply drawer and a ±12-volt duplex power supply drawer. Both power supply drawers are located directly beneath the communications interface console in figure 5.

The surveillance and CIDIN groups contain the communications interface PCB's mentioned above, plus modems and link switches, shown in figure 5. The surveillance group also includes a primary radar interface, shown in equipment rack unit 13 of figure 5.

STATUS AND MAINTENANCE FORM.

GENERAL. Failure and maintenance data as well as changes in status conditions will be entered on a specially designed status and maintenance form developed for use with the DABS sensor and the additional equipment to be evaluated. This form, shown in figure 6, is patterned after the System Maintenance Log developed by IBM for use with their 9020 equipment. It has been specifically adapted to the DABS major equipment configuration and modified for use with the ARAP.

The columns on the status and maintenance form correspond to the major units or drawers of the DABS sensor. In order to keep the form from becoming unwieldy, related units or drawers are grouped together in one column. For example, the seven ensembles of the ensemble group are grouped together under the ENSEM column of the form. This column includes the Tilines, couplers, and the 28 DABS computers contained within these seven ensembles. The 29th and 30th computers of the ensemble group are physically contained within the ATCRBS drawer and are included in the ATCRBS column of the status and maintenance form. Reference to a specific element or unit contained within a column is provided by means of SERIAL NUMBER and COMMENTS columns on the form.

The operational status of each equpment unit is shown by one of four symbols. "U," or uptime, indicates that the unit is energized and subjected to normal

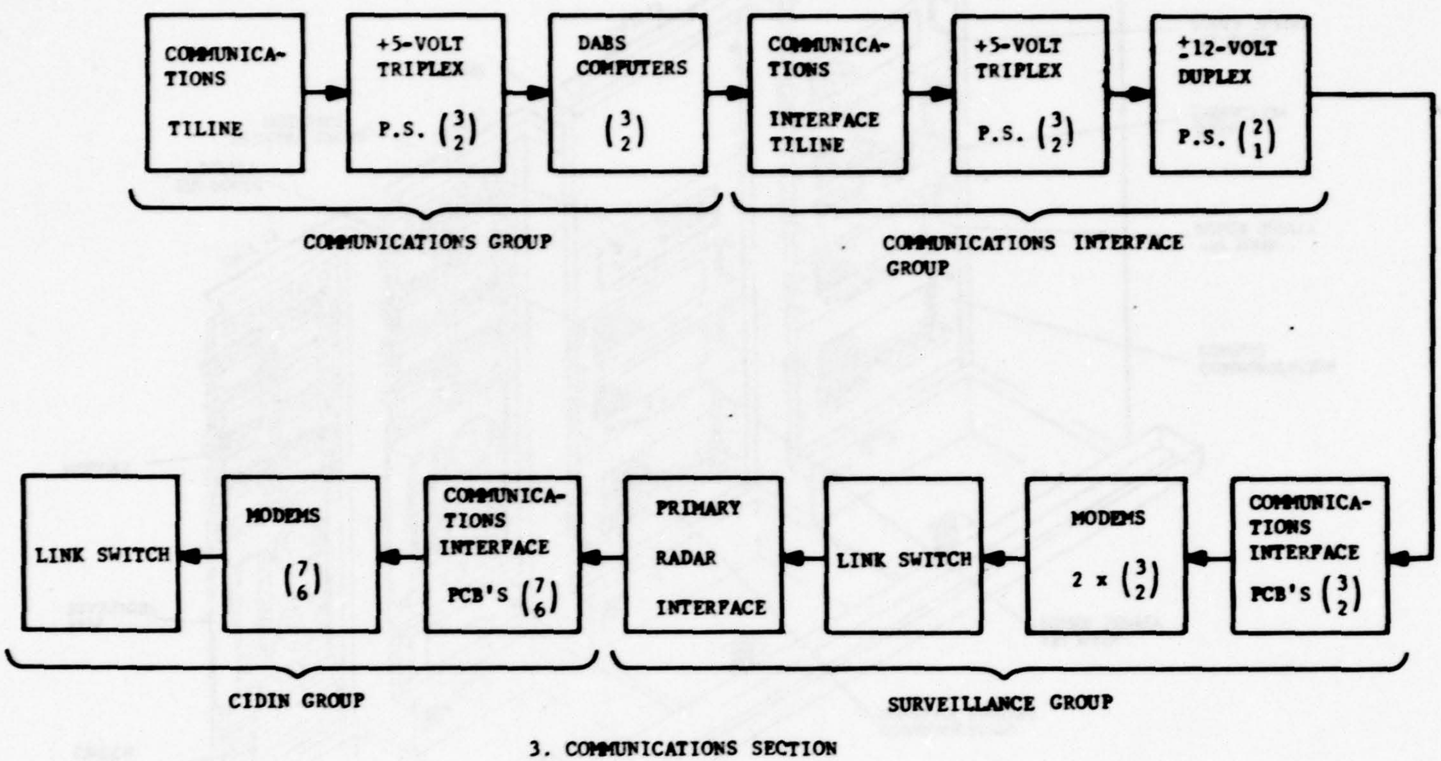


FIGURE 4. RELIABILITY MODEL OF COMMUNICATIONS SECTION OF SINGLE-CHANNEL SENSOR

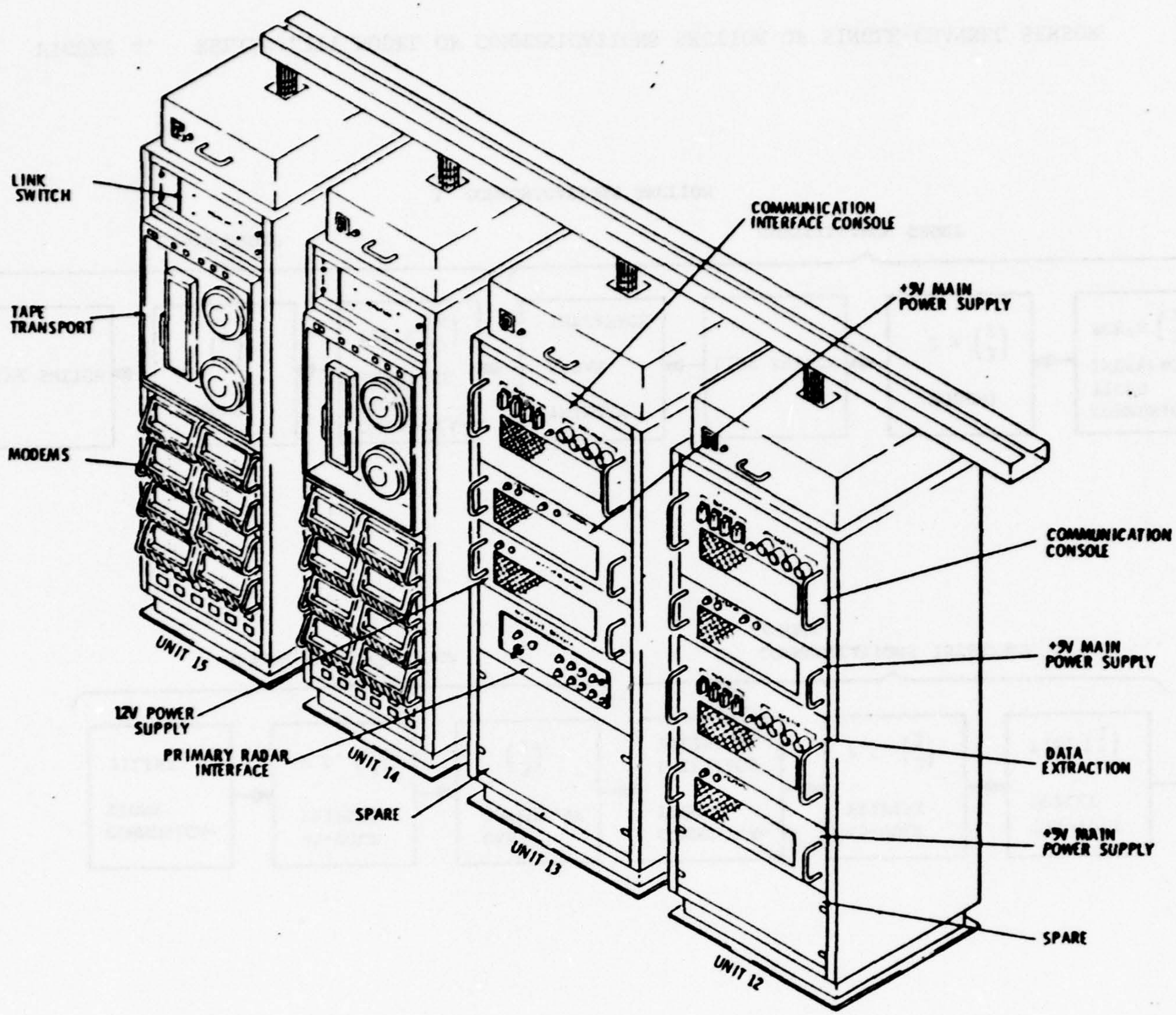


FIGURE 5. ARTIST'S CONCEPTION OF COMMUNICATIONS SECTION OF SINGLE-CHANNEL SENSOR

STATUS CODES   U - UPTIME   E- ENGINEERING CHAN
C- CORRECTIVE MAINTENANCE TIME   O- OTHER

TIME	INCIDENT NUMBER MON	DAY	YEAR	TIME	SERIAL NUMBER	AIR CON	ANTEN	XMTR	RECV	PROC	WWVB	ENSEM	ATCRBS	5 V. P.S.	12 V. P.S.	GLOBAL	COMM	COM I/F	LINK	MODEMS	PRI	FEP	STC	PSE			PART D QTY	PART NUMBER
00 00					24	U	U	U	U	U	U	U	U	E	U	U	U	U	U	U	U	U	U	U				
00 00														U														
04 13	1	1	79	04 13	1					C																	1	885581-1
04 58	1	1	79	04 13	1					U																		
08 00								O																				
09 15	1	1	79	09 15	1								O															
09 30					24									U														
09 30	1	1	79	09 30	4												O											
12 00								U																				
18 00																	O											
18 15	1	1	79	09 30	4												C										1	328579-1
18 45	1	1	79	09 30	4												O											
20 00	1	1	79	20 00	3113							C															1	323784-1
20 35	1	1	79	20 00	3113							U																
22 00																	U											
24 00																												

FIGU

…NEERING CHANGES

…E O- OTHER TIME

S T E	P S E	QTY	PART DATA: PART NUMBER	PART DATA: PART LOCATION	DOWN TIME (HRS)	OFF-LINE REP. TIME (HRS)	LOCATION: NAFEC — DATE: 1/1/79 — PAGE: 1 — COMMENTS
U	U						EC #3-78 ON ATCRBS +5V. P.S. SER. # 24
							REMAINING +5V. P.S.'s UP
		1	885581-1	A177	.7	1.5	BAD XYZ CHIP ON DABS MSG. PROC. PCB
							REPAIRED- DABS PROC. BACK ON LINE
							POWERED DOWN FOR P.M.
							PERF. MON. SHOWS ATCRBS COMPUTER #1 FAILED.
							WILL TROUBLESHOOT NEXT AVAILABLE P.M.
							EC#3-78 ON ATCRBS +5V. P.S. #24 FINISHED
							CIDIN COMPUTER OUT. WILL REPAIR NEXT P.M.
							END P.M. ON XMTR
							BEGAN PM ON COMM. CONSOLE - DEENER-
							GIZED COMM. TILINE
		1	328579-1	IN14	.5	1.0	BAD AU BOARD IN CIDIN COMPUTER.
							REPLACED DEFECTIVE LMN CHIP
		1	323784-1	B211	.6	1.0	NO ENS-2 OUTPUT TO GLOBAL A. BEGAN
							TROUBLESHOOTING. APPLIED DIAGNOSTIC ROUTINE
							G-4A AND OBSERVED WAVEFORMS. DEFECTIVE
							COUPLER TO ATCRBS TILINE. SHUT DOWN
							ENS-2 TILINE & REPLACED COUPLER. BAD
							RST CHIP IN COUPLER.
							END P.M. ON COMM CONSOLE - REENERGIZED
							END OF DAY

FIGURE 6. DABS STATUS AND MAINTENANCE FORM

2

electrical stress. This includes preventive maintenance time unless the unit is deenergized during such preventive maintenance. "C" is corrective maintenance time and includes all time that a unit is down due to a hardware failure. "E" indicates an engineering change, while "O" or "other time" includes administrative shutdown, power outages, etc.

The form includes part data and comments for use in failure documentation, together with columns for identifying each failure incident by date and time of occurrence. Columns are also provided for recording downtime and offline repair time. The use of the status and maintenance form is described in detail below. A new form should be used each day.

USE: Figure 6 illustrates the events of a typical day. At the beginning of each day, the status of the equipment units or drawers represented by each column is shown. Thus, a "U" is entered at time 0000 (midnight) for each column except the 5-V PS column. Note from figure 6 that an engineering change (E) was in process at that time for power supply No. 24 in the ATCRBS PS drawer. All the remaining 5-volt power supplies in the sensor were in an operative or "U" condition at this time and are so indicated in the second line of figure 6. The engineering change on power supply No. 24 was completed at 9:30 a.m., and is so indicated on the form.

At 4:13 a.m., a hardware failure occurred in the PROCESSOR drawer; thus, a "C" is entered in the PROC column, together with the time (0413). The "INCIDENT NO." columns uniquely identify the hardware failure by noting the date and time it first occurred. This facilitates any subsequent reference to this hardware failure. The failure was isolated to the DABS message processor PCB, part No. 885581-1, located in slot A177 (assumed) of the processor. This defective PCB was replaced, and the processor was restored to normal operation at 4:58 a.m. This is indicated on the form by the "U" entered under the PROC column at the time 0458. Note the INCIDENT NO. (1-1-79-04-13) indicating the date and time this failure occurred. The incident number is entered at the time the failure occurred (0413) and also at the time when normal operation of the processor was restored (0458). Under the column marked, "DOWNTIME," the actual corrective maintenance time is entered to the nearest tenth of an hour. This time begins when maintenance personnel actually start troubleshooting the failure and ends when the defective part has been repaired or replaced and normal operation restored. This maintenance time does not include waiting or other nonactive time. Where maintenance time is discontinuous, an estimate of total time shall be given. In this case, 0.7 hour of actual maintenance effort was expended up to the replacement of the defective message processor PCB and restoration of the processor to normal operation. The defective PCB was then further repaired offline, and the failure was isolated to a defective XYZ chip. This offline repair time took 1.5 hours and is entered in the corresponding column, while the details of the failure, troubleshooting procedures, unusual difficulties, etc., are entered under COMMENTS.

The transmitter was powered down for 4 hours of preventive maintenance from 0800 to 1200 hours. This is indicated by an "O" under the XMTR column at 0800 hours, followed by a "U" at 1200 hours.

At 9:15 a.m., a failure in ATCRBS computer No. 1 was indicated by the performance monitor. This is one of the two redundant ATCRBS computers. If the PCB's comprising this failed computer were to be removed from the ATCRBS Tiline for troubleshooting purposes while that Tiline was energized, undesirable spikes or transient effects would result; therefore, the Tiline must first be deenergized before the PCB's are removed. However, to deenergize the ATCRBS Tiline would render the DABS sensor functionally inoperative; therefore, the failed computer PCB's are left attached to the ATCRBS Tiline until a convenient time occurs when the system can be powered down for maintenance. Under worst-case conditions, this would occur at the next 30-day scheduled maintenance period, at which time the Tiline may be deenergized for up to 6 hours for troubleshooting of this failure. Since actual corrective maintenance procedures will not start until the ATCRBS Tiline is deenergized, the failure is coded "O" for "other," or neutral time, in the ATCRBS column until the Tiline is deenergized. The status will then be changed to "C" during the actual time that corrective maintenance procedures are applied to ATCRBS computer No. 1.

At 9:30 a.m., the CIDIN computer (serial No. 4) in the communications console failed. This is similar to the ATCRBS computer failure described above, in that its function is taken over by a redundant computer and will be repaired during the next scheduled maintenance period, which occurs at 1800 the same day. Therefore, the symbol "O" is entered under the COMM column at 0930 hours, indicating that computer No. 4 in the communications console is in a neutral status. All other elements in the communications console are operational (U) at this time. At 1800 hours, the entire communications console was deenergized for scheduled maintenance. This is indicated by an "O" under the COMM column at 1800 hours with appropriate notation in the COMMENTS column. Corrective maintenance procedures on the defective CIDIN computer actually started at 1815 hours, and the status code for this computer changed accordingly to "C." Repair of this computer took 30 minutes; therefore, at 1845 hours the status of the CIDIN computer returned to "O" since scheduled maintenance of the communications console continued until 2200 hours.

At 2000 hours a failure occurred in the ensemble No. 2 Tiline wherein there was no output from that ensemble to global memory A. As mentioned previously, a Tiline is a motherboard or master connection board into which are plugged couplers and other PCB's. The couplers are the means of transferring data from one Tiline to another. They come in pairs, each coupler of a pair being connected into one of the two Tilines between which data are to be transferred. In the case of this failure, diagnostic procedures indicated that the coupler attached to ensemble No. 2 in the coupler pair connecting that coupler to the global A Tiline was defective. The ensemble No. 2 Tiline was accordingly deenergized and the defective coupler replaced. Subsequent offline analysis showed a bad RST chip in the coupler.

DATA PROCESSING AND ANALYSIS

GENERAL.

After the data have been collected, they will then be encoded onto punched cards for processing and tabulation by the ARAP. The ARAP consists of three program segments. The first segment provides summaries of the operational status of each of the 200+ reliability elements and the 20 element types over the period of observation. The second program segment provides a summary of the hardware failures incurred by each of the 200+ reliability elements over the period of observation. The third program segment provides a summary of descriptive data for each failed part or component involved in a hardware failure.

These summaries will then be analyzed, in order to eliminate dependent or secondary failures or any other data which appear to be unreasonable or inordinate. The corrected hardware failure and part history summaries will then be analyzed to identify any problem areas in equipment design as evidenced by distinct or repetitive failure patterns or, in ease of maintenance, as evidenced by unusual difficulties encountered in affecting repairs. The corrected total uptimes and downtimes for each element type (obtained from the status summaries) and the total number of hardware failures for each element type (obtained from the hardware failure summary) will then be applied to a calculator where element type, section, and system failure rates and MDT's will be calculated.

CODING FOR ARAP.

Each of the more than 200 reliability elements will be uniquely identified by means of a header card. These header cards, in conjunction with appropriate trailer cards, will be used for the generation of the ARAP operational status and hardware failure summaries. They will also be used for the generation of configuration control listings.

Encoded upon each header card will be the element type, DABS site, element serial number, and an element identity (ID) code which will be unique for each of the 200+ elements. A typical header card may appear as follows:

Element Type:	COUPLER
DABS Site:	NAFEC
Element Serial Number:	23
Element ID:	H17

This header card tells us that coupler serial No. 23 is assigned element ID code H17. The H17 specifically identifies this element, since another element, such as a Tiline, may also have a serial number of 23 but would have a different ID code.

This ID code (H17) will be used with trailer cards upon which the various operational states of the corresponding element over the period of observation will be encoded. The ID code (H17) will also be used with other trailer cards upon which hardware failure information for the corresponding element will be encoded. Finally, the ID codes will be used to identify the associated elements with configuration control information. This will be described in greater detail in the following section.

CONFIGURATION CONTROL. Although not a part of ARAP as it presently exists, the header cards used with the ARAP programs can be used to generate configuration control listings. These, in turn, will be useful if not actually necessary for encoding element status and hardware failure information from the status and maintenance form.

To illustrate how the header cards can be used for the generation of configuration control listings, let us assume that the coupler serial No. 23 is plugged into global Tiline A and connects with the coupler plugged into the ensemble 1 Tiline of the computer subsystem. A configuration control trailer card would be prepared bearing the following information:

Element ID: H17
Configuration Control Data: FROM: GLOBAL A TO: ENSEMBLE 1

When used with the appropriate header card, the following printout would be obtained:

CONFIGURATION CONTROL LISTING

Element Type	Serial Number	DABS Site	Configuration Control Information
Coupler	23	NAFEC	From: Global A To: Ensemble 1

The other coupler in this coupler pair would read:

From: Ensemble 1 To: Global A

By use of such a configuration control listing, the elements associated with each column on the status and maintenance form (figure 6) can be ascertained. For example, the GLOBAL column includes global Tilines A and B, together with all the elements connected to them. Each global Tiline contains 10 couplers; 7 of which go to the 7 ensemble Tilines, 2 of which go to the ATCRBS and communications Tilines, and 1 of which goes to the opposite global Tiline. In addition, the global A Tiline includes four 176k memories, one memory monitor PCB, and four interface PCB's which interface with the DABS processor, the MCU, the performance monitor, and the azimuth system timing unit (AZSTU). The global B Tiline includes two 176k memories and one memory monitor PCB in addition to the 10 couplers mentioned above.

Each memory monitor PCB contains four reliability elements; two series elements and two switching elements. One switching and one series element are used for each pair of 176k memories. Since there is only one pair of 176k memories in global Tiline B, only one series and one switching element are used in the memory monitor PCB in the Global B Tiline. Thus, the GLOBAL column on the status and maintenance form includes the status, failure, and maintenance reporting of 2 Tilines and 36 reliability elements connected to these two Tilines. The configuration control listing of these 38 elements might appear as shown in table 2. Note that several of the couplers have the same serial number as the interface PCB's; however, the element ID codes by which header and trailer cards are related prevent any ambiguity.

Configuration control listings such as shown in table 2 identify the specific elements associated with each major equipment subunit and will be an aid to the encoding of the status, failure, and maintainability information from the columns of the status and maintenance form.

For summarizing status condition and hardware failure information for each of the 20 element types, the configuration control listings can be re-sorted so that they list all the elements of an element type together. For example, all 42 couplers with their serial numbers and configuration control information can be listed together under the coupler element type. This can also include spares. Updating of the configuration control listings due to configuration changes, element or part substitutions, etc., can be quickly and simply accomplished by inserting new trailer cards reflecting the updated configuration for the elements concerned.

OPERATIONAL STATUS. Status coding is done for each of the 200+ elements in each DABS sensor. Status information is obtained from the columns of the status and maintenance form. When the columns represent a single element, the elements are coded directly from the column; i.e., transmitter, receiver, etc. When the column represents multiple elements such as the GLOBAL column, use of the configuration control listings such as table 2 will help identify the elements concerned.

Changes in operational status are encoded upon trailer cards. Each trailer card accommodates six status conditions. Each status condition includes the status code (U, E, C, or O) together with the month, day, and time (in hours and minutes) associated with the status condition. The trailer card also includes the element ID code and the last digit of the year relating to the status data.

To illustrate status coding, let us consider a 31-day period of observation extending from July 21 through August 20, 1979. Let it be assumed that six changes in status occurred for air-conditioner serial No. 50001 during this 31-day period. This requires eight status entries, including the status conditions existing at the beginning and ending times of the 31-day period. Two trailer cards would be needed to accommodate these eight status conditions. These trailer cards would appear as follows:

TABLE 2. CONFIGURATION CONTROL LISTING OF RELIABILITY ELEMENTS OF "GLOBAL" COLUMN OF STATUS AND MAINTENANCE FORM

Element Type	Serial No.	DABS Site	Configuration Control Information
Tiline	42	NAFEC	Global A
Tiline	41	NAFEC	Global B
Coupler	23	NAFEC	From: Global A To: Ensemble 1
Coupler	24	NAFEC	From: Global A To: Ensemble 2
Coupler	29	NAFEC	From: Global A To: Ensemble 3
Coupler	25	NAFEC	From: Global A To: Ensemble 4
Coupler	27	NAFEC	From: Global A To: Ensemble 5
Coupler	26	NAFEC	From: Global A To: Ensemble 6
Coupler	28	NAFEC	From: Global A To: Ensemble 7
Coupler	30	NAFEC	From: Global A To: Global B
Coupler	32	NAFEC	From: Global A To: ATCRBS
Coupler	31	NAFEC	From: Global A To: Comm.
Coupler	51	NAFEC	From: Global B To: Ensemble 1
Coupler	52	NAFEC	From: Global B To: Ensemble 2
Coupler	53	NAFEC	From: Global B To: Ensemble 3
Coupler	54	NAFEC	From: Global B To: Ensemble 4
Coupler	55	NAFEC	From: Global B To: Ensemble 5
Coupler	56	NAFEC	From: Global B To: Ensemble 6
Coupler	57	NAFEC	From: Global B To: Ensemble 7
Coupler	58	NAFEC	From: Global B To: Global A
Coupler	59	NAFEC	From: Global B To: ATCRBS
Coupler	60	NAFEC	From: Global B To: Comm.
Interface PCB	23	NAFEC	From: Global A To: DABS Proc.
Interface PCB	25	NAFEC	From: Global A To: MCU
Interface PCB	27	NAFEC	From: Global A To: Perf. Mon.
Interface PCB	26	NAFEC	From: Global A To: AZSTU
M.M. Switch	100	NAFEC	Global A
M.M. Serial	100	NAFEC	Global A
M.M. Switch	101	NAFEC	Global A
M.M. Serial	101	NAFEC	Global A
M.M. Switch	102	NAFEC	Global B
M.M. Serial	102	NAFEC	Global B
176k Memory	70	NAFEC	Global A
176k Memory	71	NAFEC	Global A
176k Memory	72	NAFEC	Global A
176k Memory	73	NAFEC	Global A
176k Memory	74	NAFEC	Global B
176k Memory	75	NAFEC	Global B

ID	Yr	1st Status	2nd Status	3rd Status	4th Status	5th Status	6th Status
A 1	9	U 7210000	0 7301125	U 7301145	E 7312200	U 7312210	0 8 41810
A 1	9	U 8 42400	U 8202400				

The A 1 is the element ID for air-conditioner serial No. 50001. The "9" is the last digit of the year 1979. These two trailer cards, preceded by the corresponding header card, would be applied as inputs to the status summary segment of the ARAP, along with similar groups of status trailer cards for the remaining elements in the system. Each set of trailer cards must be preceded by the header card for the element concerned.

There are two parts to the element status time summary printouts. Part 1 shows the time each status condition occurred for each element and the time interval spent in each status condition. Part 2 is a summary of the total time spent in each of the four status codes by each individual element and each of the 20 element types.

A sample of the part 1 status time summary is shown in table 3. This shows the eight status times of air-conditioner serial No. 50001 which were encoded onto the two status trailer cards as discussed in the preceding paragraphs. Similar status conditions are also shown for air-conditioner No. 50002 (the second air-conditioner in the I&P section), both link switches, and the primary radar interface.

Looking at air-conditioner No. 50001, the first line reads 7-21-0-0 under the date-time group. This is 0000 hours of July 21, 1979, the start of the observation period, and corresponds to the first status entry on the first trailer card. The unit was in an operational or "U" condition until 1125 hours of July 30 (second status entry on the first trailer card). At this time, the status of the air-conditioner changed from "U" to "O." The time interval to this change in status was, therefore, 227 hours and 25 minutes and is shown in table 3 as the time interval for the first status condition (U). By a similar process, the time interval for each status condition of each element in the period of observation is obtained.

An example of part 2 of the status time summary printout is shown in table 4. This shows the total time (in hours and fractions) that each of the five elements shown in table 3 spent in each of the four status codes, as well as the total time spent in these status codes by each of the three element types represented by these five elements. Since there are two air-conditioners, two link switches, and one primary radar interface in the system, the totals for each of these three element types are shown. For example, the link switch element type showed a total "U" (uptime) of 1,475 hours, and a total downtime "C" of 1.08 hours.

HARDWARE FAILURES. Each hardware failure will be encoded upon two trailer cards, since the amount of information associated with each failure cannot be fitted upon one card. The first trailer card will contain the following information: element ID code, element type code, date and time that the failure

TABLE 3. ELEMENT STATUS TIME SUMMARY, PART 1

ELEMENT TYPE	LOCATION	SERIAL NO	YR	MO	DAY	HR	MIN	STATUS	TIME INTERVAL HRS	TIME INTERVAL MIN
AIR COND	NAF	50001	9	7	21	0	0	U	227	25
AIR COND	NAF	50001	9	7	30	11	25	O	0	20
AIR COND	NAF	50001	9	7	30	11	45	U	34	15
AIR COND	NAF	50001	9	7	31	22	0	E	0	10
AIR COND	NAF	50001	9	7	31	22	10	U	92	0
AIR COND	NAF	50001	9	8	4	18	10	O	5	50
AIR COND	NAF	50001	9	8	4	24	0	U	384	0
AIR COND	NAF	50001	9	8	20	24	0			
AIR COND	NAF	50002	9	7	21	0	0	U	262	10
AIR COND	NAF	50002	9	7	31	22	10	E	0	10
AIR COND	NAF	50002	9	7	31	22	20	U	91	50
AIR COND	NAF	50002	9	8	4	18	10	O	5	50
AIR COND	NAF	50002	9	8	4	24	0	U	384	0
AIR COND	NAF	50002	9	8	20	24	0			
LINKSWCH	NAF	51902	9	7	21	0	0	U	76	0
LINKSWCH	NAF	51902	9	7	24	4	0	O	0	15
LINKSWCH	NAF	51902	9	7	24	4	15	U	151	10
LINKSWCH	NAF	51902	9	7	30	11	25	C	1	5
LINKSWCH	NAF	51902	9	7	30	12	30	U	125	40
LINKSWCH	NAF	51902	9	8	4	18	10	O	5	50
LINKSWCH	NAF	51902	9	8	4	24	0	U	384	0
LINKSWCH	NAF	51902	9	8	20	24	0			
LINKSWCH	NAF	51903	9	7	21	0	0	U	354	10
LINKSWCH	NAF	51903	9	8	4	18	10	O	5	50
LINKSWCH	NAF	51903	9	8	4	24	0	U	384	0
LINKSWCH	NAF	51903	9	8	20	24	0			
PRIRADIF	NAF	11043	9	7	21	0	0	U	354	10
PRIRADIF	NAF	11043	9	8	4	18	10	O	5	50
PRIRADIF	NAF	11043	9	8	4	24	0	U	384	0
PRIRADIF	NAF	11043	9	8	20	24	0			

STATUS CODE DESCRIPTIONS

U- POWERED UP AND BEING USED OR AVAILABLE FOR USE
C- CORRECTIVE MAINTENANCE INCLUDING FAULT ISOLATION, REPAIR AND VERIFICATION
E- ENGINEERING CHANGES INCLUDING INSTALLATION OR REMOVAL AND CHECKOUT
O- POWER OFF EXCLUSIVE OF CORRECTIVE MAINTENANCE AND ENGINEERING CHANGES

TABLE 4. ELEMENT STATUS TIME SUMMARY, PART 2

ELEMENT TYPE	LOC	SER NO	U	TOT U	O	TOT O	C	TOT C	E	TOT E
			STATUS TIME (HRS.)							
AIR COND	NAF	50001	737.67		6.17		0.		0.17	
AIR COND	NAF	50002	738.00	1475.67	5.83	12.00	0.	0.	0.17	0.33
LINKSWCH	NAF	51902	736.83		6.08		1.08		0.	
LINKSWCH	NAF	51903	738.17	1475.00	5.83	11.92	0.	1.08	0.	0.
PRIRADIF	NAF	11043	738.17	738.17	5.83	5.83	0.	0.	0.	0.

STATUS CODE DESCRIPTIONS

U- POWERED UP AND BEING USED OR AVAILABLE FOR USE
C- CORRECTIVE MAINTENANCE INCLUDING FAULT ISOLATION, REPAIR AND VERIFICATION
E- ENGINEERING CHANGES INCLUDING INSTALLATION OR REMOVAL AND CHECKOUT
O- POWER OFF EXCLUSIVE OF CORRECTIVE MAINTENANCE AND ENGINEERING CHANGES

first occurred, description of the failure, time to unit restoration (downtime), offline repair time (if applicable), number of parts associated with the maintenance action, and a card indentification number. The second trailer card will contain the element ID code; the same card identification number that was assigned to the first trailer card; the number, type, and/or location of the part associated with the maintenance action; and the disposition of the part, such as repaired, replaced, cleaned, adjusted, or shipped. The date and month that this action took place should also be noted. The failure information encoded on these two trailer cards is obtained from the status and maintenance form. The two trailer cards associated with each failure must be preceded by the associated header card for processing by the ARAP. The header card and two trailer cards associated with the processor failure occurring at 0413 hours (figure 6) would appear as shown in figure 7. A sample of a hardware failure summary printout is shown in table 5.

PART FAILURES. Each part failure is coded upon a single punched card. The information to be encoded shall include a part type code; number, type, and/or location of the failed part; the element type associated with the failed part; the DABS site number; a description of the part failure, such as "defective ABC chip;" and a disposition code as follows: A-repaired, B-adjusted, C-cleaned, D-thrown away, and E-shipped. A card ID shall also be encoded. An example of a part failure summary is shown in table 6.

REVISED ARAP. The ARAP was originally designed for the 7090 system, containing about 20 to 30 discrete equipment units. Each DABS sensor contains over 200 reliability elements. The status changes of each of these must be encoded over a definite period of observation. While many of these elements will require few or no status changes over the period of observation, especially if the system is continuously energized, still header and trailer cards must be coded for each of these elements. As many of the elements associated with certain columns on the status and maintenance forms must be identified through the configuration control listings, this involves an additional workload, particularly for status encoding. When encoding hardware failures, a header card must accompany the two trailer cards of each hardware failure, even though several different failures occur in the same element. This requires many duplicates of the header cards to be made.

Attempts will be made to streamline and simplify the ARAP program for DABS application. This would mean that one header card placed anywhere within the data card deck could be used for the status and all hardware failures associated with any particular element. By including the configuration control trailer cards in the revised ARAP, the workload involved in the status encoding can be virtually reduced to the total number of columns on the status and maintenance forms rather than encoding each of the 200+ elements. This could be accomplished by using a composite trailer card for each column on the maintenance form. This composite trailer card would include all the elements contained in that column. A status change applicable to one element in that column grouping could be indicated by a supplementary trailer card indicating that particular status condition. As an example of this, consider the GLOBAL column of the status and maintenance

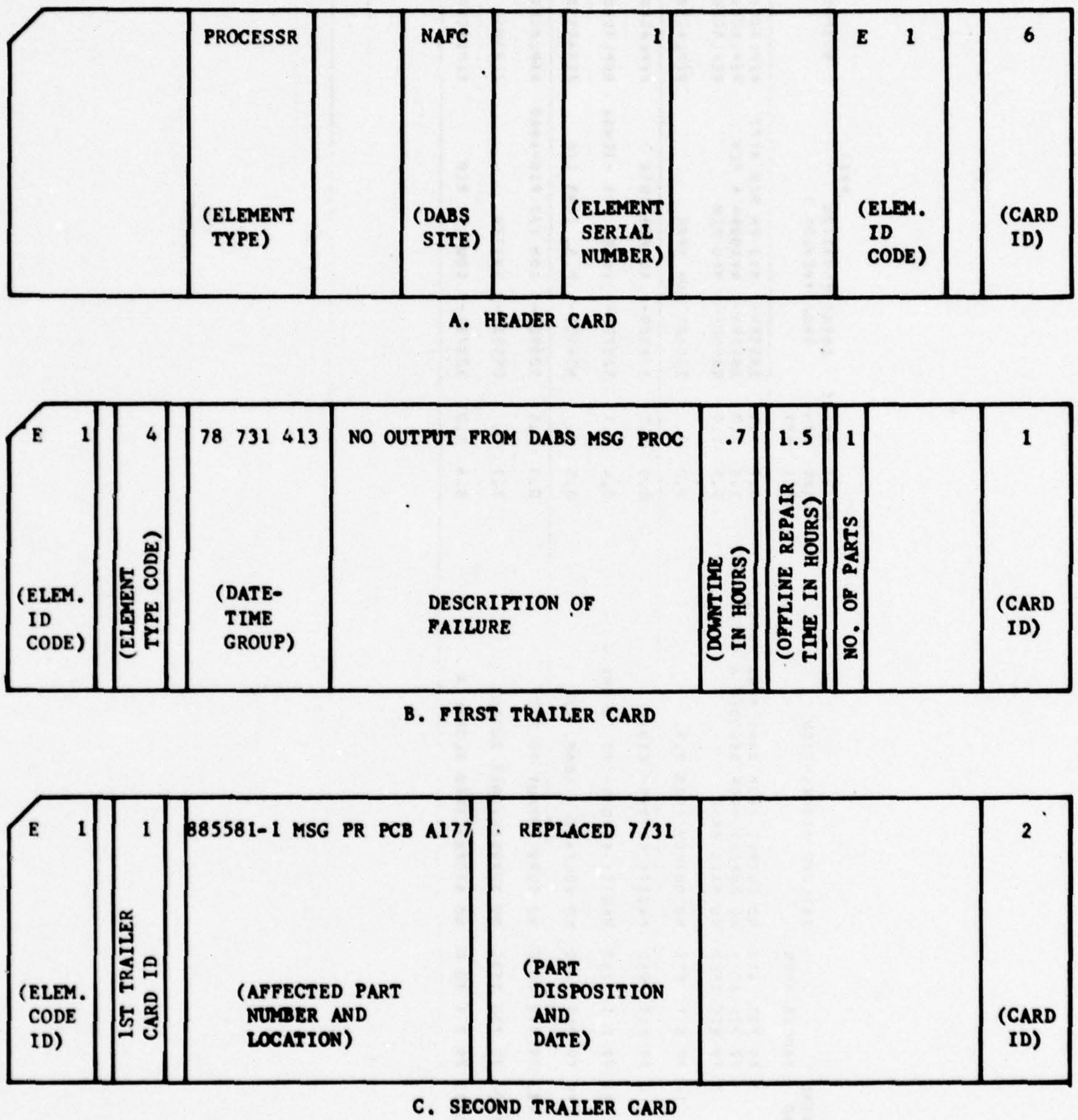


FIGURE 7. HEADER AND TRAILER CARDS FOR TYPICAL DABS HARDWARE FAILURE

TABLE 5. DABS HARDWARE FAILURE SUMMARY

ELEMENT TYPE	LOC	SERIAL NO	YRMODA	HRMN	FAILURE DESCRIPTION	MAINT TIME (HRS)	MAINT MAN-HRS	PART IDENTIFICATION (NO/TYPE/LOC)	DISPOSITION
PROCESSR	NAFC	1	79 731	413	NO OUTPUT FROM DABS MSG. PROC.	0.7	1.5	885581-1 MSG PR PCB A177	REPLACED 7/31
PROCESSR	NAFC	1	79 731	1015	NO OUTPUT FROM DECODER A ATCRBS PR.	1.0	2.0	885596-1 DECODER A PC3	REPLACED 7/31
PROCESSR	NAFC	1	79 815	1362	NO MAIN BANG	1.5	1.0	885605-1 MCU PCB	REPLACED 8/15
WWVB REC	NAFC	14	79 8 1	835	NO OUTPUT FROM P.S.	2.0	0.	224681 PWR XFMR	REPLACED 8/ 1
COMPUTER	NAFC	4	79 715	930	PARITY ERRORS- CIDIN	0.5	1.0	328579-1 AU PCB IN14	REPLACED 7/15
COMPUTER	NAFC	27	79 7 1	1130	PARITY ERRORS- #3 IN ENS 4 -	0.4	1.1	323778-1 VOTER PC3 -3ENS4	REPLACED 7/ 1
+5V P.S.	NAFC	19	79 715	1445	NO VOLTAGE - COMM. I/F	0.5	0.	804108-1 P.S. COMM I/F	REPAIRED 7/15
COMIFSER	NAFC	132	79 715	20 0	NO SURV OUTPUT TO TATF	0.3	1.5	323802-1 COM I/F PCB-4N68	REPLACED 7/15
LINKSWCH	NAFC	51902	79 730	1125	NO SURVEILLANCE OUTPUT	1.1	0.	051552-2 SWITCH	CLEANED 7/30
COUPLER	NAFC	3113	79 7 1	20 0	NO ATCRBS INTO GLOBAL A	0.6	1.0	323784-1 COUPLER PCB	REPLACED 7/ 1

TABLE 6. DABS PART FAILURE SUMMARY

PART IDENTIFICATION (NO./TYPE/LOC.)	ELEMENT TYPE	ELEMENT LOC.	PART FAILURE DESCRIPTION	DISPOSITION
051552-2 SWITCH	LINKSWCH	NAFC	CORRODED CONTACTS	CLEANED
224681 PWR XFMR	WWVB REC	NAFC	BURNED OUT	THROWNAWAY
804108-1 P.S. COM I/F	+5V P.S.	NAFC	OPEN CR-1	REPAIRED
323778-1 VOTER PCB 3ENS4	COMPUTER	NAFC	BAD OPQ CHIP	REPAIRED
323784-1 COUPLER PCB	COUPLER	NAFC	BAD RST CHIP	REPAIRED
323802-1 COM I/F PCB 4N68	COMIFSER	NAFC	BAD WYZ CHIP	REPAIRED
328579-1 AU PCB IN14	COMPUTER	NAFC	BAD LMN CHIP	REPAIRED
885581-1 MSG PR PCB A177	PROCESSR	NAFC	BAD XYZ CHIP	REPAIRED
885596-1 DECODER A PCB	PROCESSR	NAFC	LEAKAGE IN Q3	REPAIRED
885605-1 MCU PCB	PROCESSR	NAFC	BURNED OUT Q7	REPAIRED

form. As seen in table 2, this contains 38 elements. A composite trailer card would be encoded with the overall status of all 38 elements. Should one of these elements; for example, the Interface PCB for the DABS processor , fail on a certain date, a supplementary trailer card would be made out for this element indicating its failed status for the appropriate time on that day.

SUBSEQUENT PROCESSING.

GENERAL. Having obtained the total uptimes, downtimes, and numbers of failures for each element and element type from the ARAP printouts, these data will then be analyzed for inordinate or unreasonable values. This analysis will include a statistical test which will test the assumption that each element type exhibits a constant failure and repair rate. This is done because the mathematical models which are used to compute the element type, section, and system failure rates assume a constant failure and repair rate (exponential distribution) for each element type. This test, known as the Kolmogorov-Smirnov goodness-of-fit test, has been programed as have other statistical tests which will be used to test the assumption that all elements within each element type are from the same statistical population.

The uncorrected total uptimes and downtimes for each element type are obtained from the "TOT U" and "TOT C" columns, respectively, of the element status time summary part 2 (table 4), while the uncorrected number of failures is obtained from the hardware failure summary of table 5. After removing data which do not meet the required statistical criteria, the corrected value will then be applied to the calculator, where element type section and system failure rates and MDT's will be computed and printed out. The MTBF for the entire DABS system will also be calculated and printed out. These values will be printed on a summary form similar to that shown in table 7 for the single-channel sensor. Note that the element type failure rates and MDT's shown in table 7 are hypothetical values used for illustrative purposes only. They are actually the predicted values used by TI in their reliability model to calculate the predicted MTBF as required by the ER. These predicted values will be used in this paper in the mathematical models to follow for illustrative purposes only. They are not to be construed as actually measured values.

In using the summary form of table 7, the site, beginning and ending dates of the observation period, and maximum time to replacement of failed PCB's (next convenient time to effect repairs) are entered manually. The remainder of the headings are printed automatically, then the calculator stops for manual entry of element type data.

ELEMENT TYPE SUMMARY. In generating the element type summary, the calculator automatically prints the name of the element type being processed, then stops. The corrected values of total uptime, number of failures, and total downtime for that element type are then each entered in turn. From these three entries, the calculator computes the failure rate per million hours and the MDT for the element type concerned. The following formulas are used to generate these quantities:

TABLE 7. DABS RELIABILITY AND MAINTAINABILITY SUMMARIES

SITE: NAFEC **FROM: January 1, 1979** **TO: January 31, 1979**
MAXIMUM TIME TO REPLACEMENT OF FAILED PCB's **720 Hours**

1. ELEMENT TYPE SUMMARY

ELEMENT TYPE	TOTAL UPTIME (HOURS)	NO. OF FAILURES	TOTAL DOWNTIME (HOURS)	FAILURES PER MILLION HOURS	MEAN DOWNTIME (HOURS)
1. AIR-CONDITIONERS	14143	1	2.0	70.706	2.0
2. ANTENNA GROUP	86207	1	2.0	11.600	2.0
3. TRANSMITTER	4605	1	2.0	217.155	2.0
4. RECEIVER	4278	1	2.0	233.754	2.0
5. PROCESSOR	7673	1	2.0	130.327	2.0
6. WWVB RECEIVER	10000	0	0	0	0
7. TILINES	500000	1	2.0	2.000	2.0
8. COUPLERS	116279	1	2.0	8.600	2.0
9. INTERFACE PCB's	44964	1	2.0	22.240	2.0
10. 5-VOLT P.S.	3592	1	2.0	278.396	2.0
11. 12-VOLT P.S.	3682	1	2.0	271.592	2.0
12. DABS COMPUTERS	4666	1	2.0	214.316	2.0
13. 176-K MEMORY	7974	1	2.0	125.408	2.0
14. MEM. SWITCH ELEMENT	508906	2	4.0	3.930	2.0
15. MEM. SERIAL ELEMENT	925926	1	2.0	1.080	2.0
16. COMM. I/F - SERIAL	89928	1	2.0	11.120	2.0
17. COMM. I/F - CHANNEL	179856	1	2.0	5.560	2.0
18. MODEMS	15000	1	2.0	66.670	2.0
19. LINK SWITCHES	317460	1	2.0	3.150	2.0
20. PRI. RADAR I/F	297619	1	2.0	3.360	2.0

2. SECTION SUMMARY - SINGLE CHANNEL

	FAILURES PER MILLION HOURS	MEAN DOWNTIME (HOURS)
A. INTERROGATOR AND PROCESSOR SECTION	592.856	2.0
B. COMPUTER SECTION		
1) ATCRBS GROUP	76.508	1.3
2) ENSEMBLE GROUP	218.590	1.0
3) GLOBAL MEMORY GROUP	159.684	1.6
TOTAL COMPUTER SECTION	454.782	1.3
C. COMMUNICATIONS SECTION		
1) COMM. CONSOLE (INCLUDING COMPUTERS)	143.310	1.0
2) COMM. I/F CONSOLE (INCLUDING MODEMS)	100.973	1.3
TOTAL COMMUNICATIONS SECTION	244.283	1.1

3. SYSTEM SUMMARY - SINGLE CHANNEL 1291.921 1.7

SYSTEM MTBF **774 hours**

$$\text{Failures per million hours } (\lambda) = \frac{\text{No. of Failures} \times 10^6}{\text{Total Uptime}}$$

$$\text{MDT} = \frac{\text{Total Downtime}}{\text{No. of Failures}}$$

For the air-conditioners, these values are:

$$\text{Failures per million hours } (\lambda) = \frac{1 \times 10^6}{14143} = 70.706$$

$$\text{MDT} = \frac{2.0}{1} = 2 \text{ hours}$$

The above procedure is repeated for each of the element types. Note again that the above values in table 7 are hypothetical--they were selected in order that the resulting element type failure rates and MDT's correspond to TI's predicted values.

SINGLE-CHANNEL SECTION ANALYSIS. From the element type summary information entered by the operator, the calculator will automatically compute and print out the failure rates and MDT's for each of the three sections of the single-channel sensors, including the three computer section groups and the two communications section consoles. This is all done automatically without any further manual intervention. The mathematical models applicable to each of the three sections are described below.

Interrogator and Processor Section. The I&P section reliability model (figure 1) is the simplest of the three sections. It consists of a $\binom{2}{1}$ group of air-conditioners in series with a string of five series elements; i.e., antenna group, transmitter, receiver, processor, and WWVB receiver.

The failure rate for a string of series elements or units is simply the sum of the failure rates of the individual units or boxes comprising the string. Thus, in figure 1, the $\binom{2}{1}$ air-conditioner block must first be converted to a simple series block with equivalent failure rates and MDT's corresponding to a simultaneous failure of both air-conditioners. In other words, the hardware failures occurring in the individual air-conditioners must be converted into equivalent functional failures applicable to the $\binom{2}{1}$ redundant combination. This is done by use of the Einhorn formulas (Einhorn, E. J., "Reliability Predictions for Repairable Redundant Systems," Proceedings of the IEEE, p. 312 - February 1963) which are based upon the assumption (1) that both uptimes and downtimes for each element in the redundant combination have exponential distributions, and (2) they are independent of the conditions of the other elements. These conditions apply in the case of the two air-conditioners, so the formulas for a redundant combination of two identical elements are:

$$\lambda_{EFF} = 2\lambda^2 D$$

and $D_{EFF} = D/2$ where

λ_{EFF} = effective failure rate of redundant combination in hours

D_{EFF} = effective MDT of redundant combination in hours

λ = failure rate of one of the identical elements comprising the redundant combination, in hours

and D = MDT, in hours, of one of the identical elements comprising the redundant combination

Applying these formulas to the $\binom{2}{1}$ air-conditioners block, we get:

$\lambda_{EFF} = 2 \times (70.706 \times 10^{-6})^2 \times 2 = .02 \times 10^{-6}$ failures per hour or 0.02 failures per million hours

$D_{EFF} = 2.0/2 = 1$ hour

Thus, the $\binom{2}{1}$ air-conditioner block has been converted into an equivalent series block with an effective failure rate of 0.02 failures per million hours and an effective MDT of 1 hour. The effective failure rate of the I&P section is the sum of the failure rates of all six series blocks. This is:

Air-Conditioners (equivalent series)	0.02
Antenna Group	11.600
Transmitter	217.160
Receiver	233.750
Processor	130.330
WWVB Receiver	0.00
Total $\lambda_{I\&P}$ or λ_A =	592.860 failures per million hours

The effective MDT of the series string is given by:

$MDT_{EFF} = \Sigma(\lambda \times MDT) / \lambda_{EFF}$ where λ and MDT are the failure rates and MDT's, respectively, of each unit in the series string, and λ_{EFF} is the effective failure rate of the series string. The effective MDT of the I&P section is then:

$$= \frac{(0.02 \times 1) + (11.6 \times 2) + (217.16 \times 2) + (233.75 \times 2) + (130.33 \times 2)}{592.86}$$

= 1.9832 hours or 2.0 hours (rounded to nearest tenth)

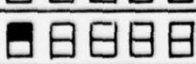
Computer Section. The computer section reliability model, shown in figure 2, consists of four groups; the ATCRBS group, the ensemble group, and global memories A and B. Since the two global memories are similar except for two extra 176k memory strings and four interface PCB's plugged into the global A Tiline, they will be combined into one global memory group for the purposes of this summary.

Figure 8 shows the DABS computer section in somewhat more detail than the reliability model of figure 2. Note the five coupler pairs so marked on figure 8. These coupler pairs are the means by which data are transferred between the ATCRBS Tiline, both global Tilines, and the communications Tiline. Should an individual coupler of one of these five pairs fail, data can still be properly transferred by means of the other four pairs; hence, this is a $\binom{5}{4}$ redundant combination. Since the ATCRBS Tiline, each global Tiline, and the communications Tiline each contains two or more members of these coupler pairs, the effective failure rate and MDT of the $\binom{5}{4}$ redundant combination must be computed and properly apportioned among these Tilines.

Since these couplers are plugged into Tilines which can only be deenergized during scheduled maintenance periods, a failed coupler must be left plugged into its Tiline until the next preventive maintenance (PM) period occurs, which is 720 hours under worst-case conditions. The procedure used is a state diagram technique, which is a generalization of the Einhorn method. Essentially, this consists of ascertaining all possible states in which the redundant group will operate and computing the probability of the redundant group being in that state for the worst case time period (720 hours). The probability associated with each state is then multiplied by the combined failure rates of the number of units which, if any one were to fail, would cause complete failure of the redundant group; hence, system failure. The effective failure rate of the redundant group is equal to the sum of these products divided by the sum of the state probabilities.

This procedure is best illustrated by the actual state diagram for the $\binom{5}{4}$ redundant coupler pairs, shown in table 8.

TABLE 8. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE OF $\binom{5}{4}$ REDUNDANT COUPLER PAIR COMBINATION

		Probability		Failure	Mode Information	
State	Configuration	Formula	Numerical Value	λ	Failure Rate	Prob. x Failure Rate
1		$P_5=e^{-u}$	$P_5=.93995808$	-	-	-
2		$P_4=Ue^{-u}$	$P_4=.0582022$	$4\lambda_c$	6.88×10^{-5}	4.0043×10^{-6}
		Total	.99816029			4.0043×10^{-6}

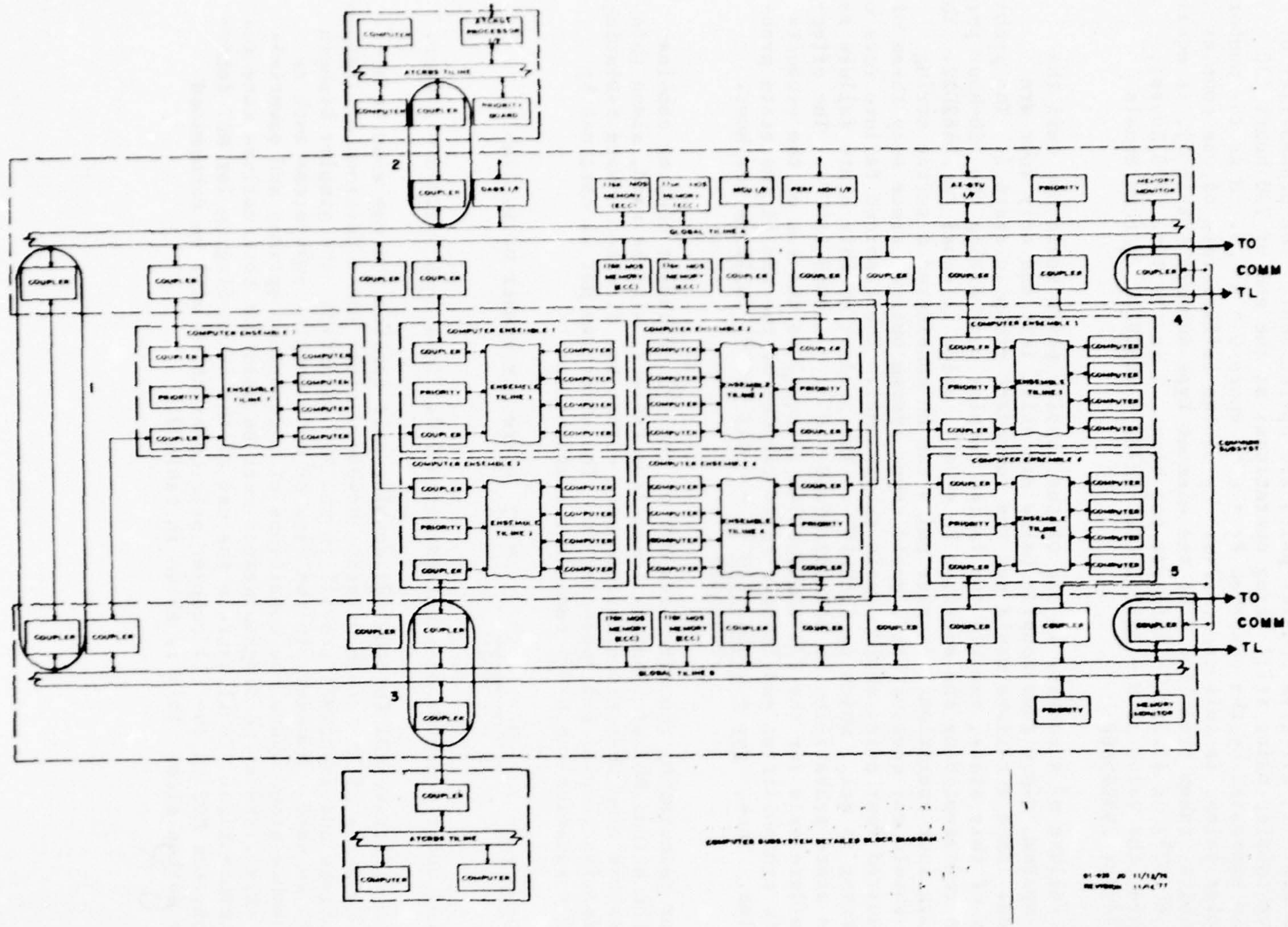


FIGURE 8. DABS COMPUTER SECTION

In state 1, all five coupler pairs are operational. The probability of all five coupler pairs still being operational at the end of 720 hours (30 days) is expressed by the equation $P_5 = e^{-U}$, where $U = N \lambda_c T$. N is the number of coupler pairs, in this case, five. λ_c is the failure rate of one coupler pair, which, taken from line 8 of the element type summary (table 7), is equal to $2x8.6(10^{-6})$ or $17.2x10^{-6}$ failures per hour. T is the time (720 hours); therefore, the value of $U = 5x17.2 (10^{-6})x720 = .06192$. P_5 then equals $e^{-.06192}$, or .93995808.

A failure of a coupler in one of the coupler pairs would not fail the entire system, since four coupler pairs are still left and only four are required. Such a failure would put the redundant group in state 2. The probability of this state, exactly one failed coupler pair during the 720-hour period, is represented by the equation $P_4 = Ue^{-U}$, which is equal to .0582022. The remaining four operational coupler pairs can be considered a series string which, should any coupler fail, would cause system outage, since only three of the required four pairs would remain operational. The combined failure rate of this string is $4x\lambda_c$, which is $6.88x10^{-5}$. The product of this state failure rate and the state probability is $.0582022x6.88 (10^{-5}) = 4.0043 (10^{-6})$. The effective failure rate for the $\binom{5}{4}$ combination is equal to the sum of the products of state probabilities and failure rates divided by the sum of the state probabilities. Thus, $\lambda_{EFF} = \frac{4.0043 (10^{-6})}{.99816029} = 4.012 (10^{-6})$ failures per hour.

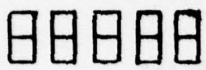
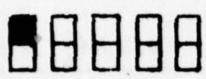
For calculating the effective MDT of the $\binom{5}{4}$ redundant coupler combination, the actual MDT of 2 hours, taken from table 7, will be used, since this reflects the time that actual maintenance effort was directed toward isolating the defective coupler and replacing it. The effective MDT is obtained by Einhorn's equation for a $\binom{5}{4}$ redundant combination:

$$D_{EFF} = \frac{D}{n - r + 1} = \frac{D}{2},$$ where n = number of available

units (5) and r = number of required units (4). Then $D_{EFF} = 2.0/2 = 1$ hour.

The effective MDT for the $\binom{5}{4}$ coupler pair combination can also be obtained by means of the state diagram; however, since the conditions of independent uptimes and downtimes prevail in the MDT situation, the simpler Einhorn equation is used. However, in the case of more complex subsystems such as the ensemble group where the conditions of independent uptimes and downtimes do not exist, the state diagram method must be used for both failure rate and MDT determination. To illustrate the use of the state diagram for MDT determination, the MDT of the $\binom{5}{4}$ coupler pair combination will be determined by this method also. This is shown in table 9.

TABLE 9. STATE DIAGRAM FOR EQUIVALENT MDT OF $\binom{5}{4}$ COUPLER PAIR COMBINATION

State	Configuration	Probability		Failure Mode Information		
		Formula	Numerical Value	λ	Failure Rate	Prob. x Failure Rate
1		p^5	.9998280177	-	-	
2		$5p^4q$	.0001719704	$4\lambda_c$	6.88×10^{-5}	1.183156494 $\times 10^{-8}$
	Total		.9999999881			1.183156494 $\times 10^{-8}$

$$MDT_{EFF} = \frac{1 - \Sigma \text{ State Probabilities}}{\Sigma \text{ (State Probabilities x State Failure Rates)}}$$

$$= \frac{1 - .9999999881}{1.183156494 \times 10^{-8}} = \frac{1.19 \times 10^{-8}}{1.183156494 \times 10^{-8}}$$

= 1.006 hours, or 1.0 hour rounded to tenths

In the above diagram, p equals the probability of a coupler pair being operational at any time. This probability can be expressed by $p = \frac{U}{U+D}$, where U and D are the MTBF and MDT, respectively, of an individual coupler pair. As the coupler pair can be considered a series string of two identical couplers, $U = \frac{1}{2 \times 8.6\ (10^{-6})}$ = 58139.535 hours; while D, the MDT of a single coupler, is 2 hours. The value of p, then, is .9999656012 while q, the probability of a coupler pair being in a failed state at any given time, is 1 - p, or 3.43988×10^{-5}.

ATCRBS Group. As seen in figure 2, the ATCRBS group consists of an ATCRBS Tiline containing a $\binom{2}{1}$ computer combination, all of which is energized by a $\binom{3}{2}$ triplex 5-volt power supply. The effective failure rates and MDT's of each of these three blocks shown in figure 2 must be calculated.

ATCRBS Tiline. The ATCRBS Tiline consists of 1 Tiline (element type 7 of table 7), 1 ATCRBS Interface PCB (element type 9 of table 7), and 2 of the 10 individual couplers comprising the $\binom{5}{4}$ coupler-pair combination. For reliability modeling purposes, the ATCRBS Tiline can be considered as a series string containing one Tiline, one interface PCB, and one-fifth of the $\binom{5}{4}$ coupler pair combination. The proportion of the effective failure rate of the $\binom{5}{4}$ coupler pair combination assigned to the ATCRBS Tiline is then 0.2 of the calculated failure rate (4.012 failures per million hours), while the entire equivalent MDT of the $\binom{5}{4}$ coupler pair combination would be assigned to each apportioned part.

$$\lambda_{B1a} = \lambda_{Tiline} + \lambda_{I/F} + 0.2 \times \lambda_{\binom{5}{4}\text{ coupler pairs}}$$

$$= 25.042 \text{ failures per million hours}$$

$$MDT_{B1a} = \frac{(\lambda_{Tiline} \times MDT_{Tiline}) + (\lambda_{I/F} \times MDT_{I/F}) + \left[0.2\,\lambda\binom{5}{4} \times MDT\binom{5}{4}\right]}{\lambda_{B1a}}$$

$$= 1.968 \text{ hours}$$

$\binom{3}{2}$ + 5-Volt triplex power supply. The effective failure rate and MDT for the $\binom{3}{2}$ 5-volt triplex power supply can be obtained by use of Einhorn's equations. These are:

$$\lambda_{EFF} = 6\,\lambda^2 D \quad \text{and} \quad MDT_{EFF} = \frac{D}{2}$$

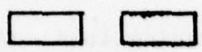
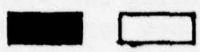
where λ and D are the failure rate and MDT, respectively, of a single 5-volt power supply (element type 10 in table 7). These values are:

$$\lambda_{B1b} = 0.93 \text{ failures per million hours}$$

$$MDT_{B1b} = D/2 = 1 \text{ hour}$$

$\binom{2}{1}$ ATCRBS computer combination. As these computers are plugged into the ATCRBS Tiline, they are not repaired immediately upon failure; hence, the 720-hour state diagram technique is used for computation of the effective failure rate. This is shown in table 10.

TABLE 10. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE OF $\binom{2}{1}$ ATCRBS COMPUTER COMBINATION

State	Configuration	Probability: Formula	Probability: Numerical Value	Failure Mode Information: λ	Failure Mode Information: Failure Rate	Failure Mode Information: Prob. x Fail. Rate
1		$P_2 = e^{-u}$	.73448038	-	-	-
2		$P_1 = Ue^{-u}$	.22665477	λ	214.3×10^{-6}	48.572×10^{-6}
	Total		.96113515			48.572×10^{-6}

where $U = N \lambda T = .308592$

Then $\lambda_{B1c} = \dfrac{48.572(10^{-6})}{.96113515} = 50.536$ failures per million hours

The Einhorn equation is used for finding the effective MDT. This is:

$MDT_{B1c} = D/2 = 1$ hour

ATCRBS group summation The effective failure rate and MDT of the ATCRBS group are as follows:

$\lambda_{B1} = \lambda_{B1a} + \lambda_{B1b} + \lambda_{B1c}$

$= 76.508$ failures per million hours

$$MDT_{B1} = \frac{(\lambda_{B1a} \times MDT_{B1a}) + (\lambda_{B1b} \times MDB_{B1b}) + (\lambda_{B1c} \times MDT_{B1c})}{\lambda_{B1}}$$

= 1.3 hours (rounded to nearest tenth)

Ensemble Group. The ensemble group consists of seven ensemble Tilines, each of which contains four computers. Two additional computers used with the ensemble group are physically attached to the ATCRBS Tiline. This provides a total of 30 computers in the ensemble group, of which 26 must be operational in order for the system to function. Normally, these will be provided by 26 of the 30 computers contained in the ensemble group. Hence, loss of up to four computers can be sustained by the ensemble group with no impact on system operation.

Should the ensemble group sustain the loss of five computers; i.e., one complete ensemble plus one additional computer, there would now be only 25 computers available in the ensemble group--1 less than the 26 required to maintain the system operational. In this case, the ensemble group will preempt the spare communications computer shown in figure 4 as the $\binom{3}{2}$ DABS computers block, provided the remaining two communications computers are functioning. Thus, the spare communications computer can perform a double function--either as a redundant communications (surveillance or CIDIN) computer or as a redundant ensemble group computer.

Since the $\binom{30}{26}$ ensemble group and the $\binom{3}{2}$ communications computer are not independent, due to the dual function of the spare communications computer, the effective failure rate of the combined ensemble group and $\binom{3}{2}$ communications computer combinations must be determined using the state diagram technique. The combined effective failure rate is then apportioned to the ensemble group and the communications computer combination in accordance with the appropriate states of the state diagrams. This procedure, which is worked out in detail in appendix A, results in an effective failure rate for the ensemble group λ_{B2} of 218.59 failures per million hours.

The state diagram technique is also used for the effective MDT determination of the ensemble group and communications computers combination. This procedure, worked out in detail in appendix A, results in an effective MDT of 1 hour for the ensemble group and communications computer combination. This effective MDT will be used for both the ensemble group and the $\binom{3}{2}$ communications computers combination. Thus, MDT_{B2} = 1 hour.

Global Memory Group. The global memory group consists of the seven boxes (Global A and B) in the lower half of figure 2.

Global Tiline A. Global Tiline A contains one Tiline and four interface PCB's. As seen in figure 8, 3 of the 10 couplers in the $\binom{5}{4}$ redundant coupler pairs are contained in the Tiline; therefore, 0.3 of the effective failure rate of the $\binom{5}{4}$ coupler group must be apportioned to Global Tiline A. Hence,

$$\lambda_{B3a} = \lambda_{TI} + 4 \quad \lambda_{I/F} + 0.3 \quad \lambda_{\binom{5}{4}}$$

$$= 92.1636 \text{ failures per million hours.}$$

$$MDT_{B3a} = \frac{(\lambda_{TI} \times MDT_{TI}) + (4 \lambda_{I/F} \times MDT_{I/F}) + \left[(0.3 \lambda_{\binom{5}{4}} \times MDT_{\binom{5}{4}})\right]}{\lambda_{B3a}}$$

$$= 1.9869 \text{ hours}$$

Global Tiline B. Global Tiline B is identical to global Tiline A except that it doesn't contain the four interface PCB's. Then:

$$\lambda_{B3b} = \lambda_{TI} + 0.3 \quad \lambda_{\binom{5}{4}}$$

$$= 3.2036 \text{ failures per million hours.}$$

$$MDT_{B3b} = \frac{(\lambda_{TI} \times MDT_{TI}) + \left[(0.3\ \lambda_{\binom{5}{4}} \times MDT_{\binom{5}{4}})\right]}{\lambda_{B3b}}$$

$$MDT_{B3b} = 1.6243 \text{ hours.}$$

$\binom{3}{2}$ Five-volt triplex power supply. As computed for λ_{B1b} on page 36,

$$\lambda_{B3c} = 0.93 \text{ failures per million hours}$$

$$MDT_{B3c} = 1 \text{ hour}$$

$\binom{2}{1}$ Memory string sets. Global Tiline A contains two sets of 176k memory strings, while global Tiline B contains one such set. Each set consists of two 176k memory strings of which one is redundant, plus one series and one switching memory monitor element. Figure 9 is a reliability diagram showing the functional arrangement of these units within each of these three sets. There is actually only one switching element, and it is needed only when switching to a redundant 176k memory string. Functionally, half the failure rate of the switching element can be apportioned to each of the two memory strings. The effective failure rate of each of the two redundant branches is then:

$$\lambda_{BR} = \lambda_{176k} + \frac{1}{2}\ \lambda_{Switch}$$

$$= 127.365 \text{ failures per million hours}$$

The effective MDT of each branch is then

$$MDT_{BR} = \frac{(\lambda_{176k} \times MDT_{176k}) + (\frac{1}{2} \times \lambda_{Switch} \times MDT_{Switch})}{\lambda_{BR}}$$

$$= 2 \text{ hours}$$

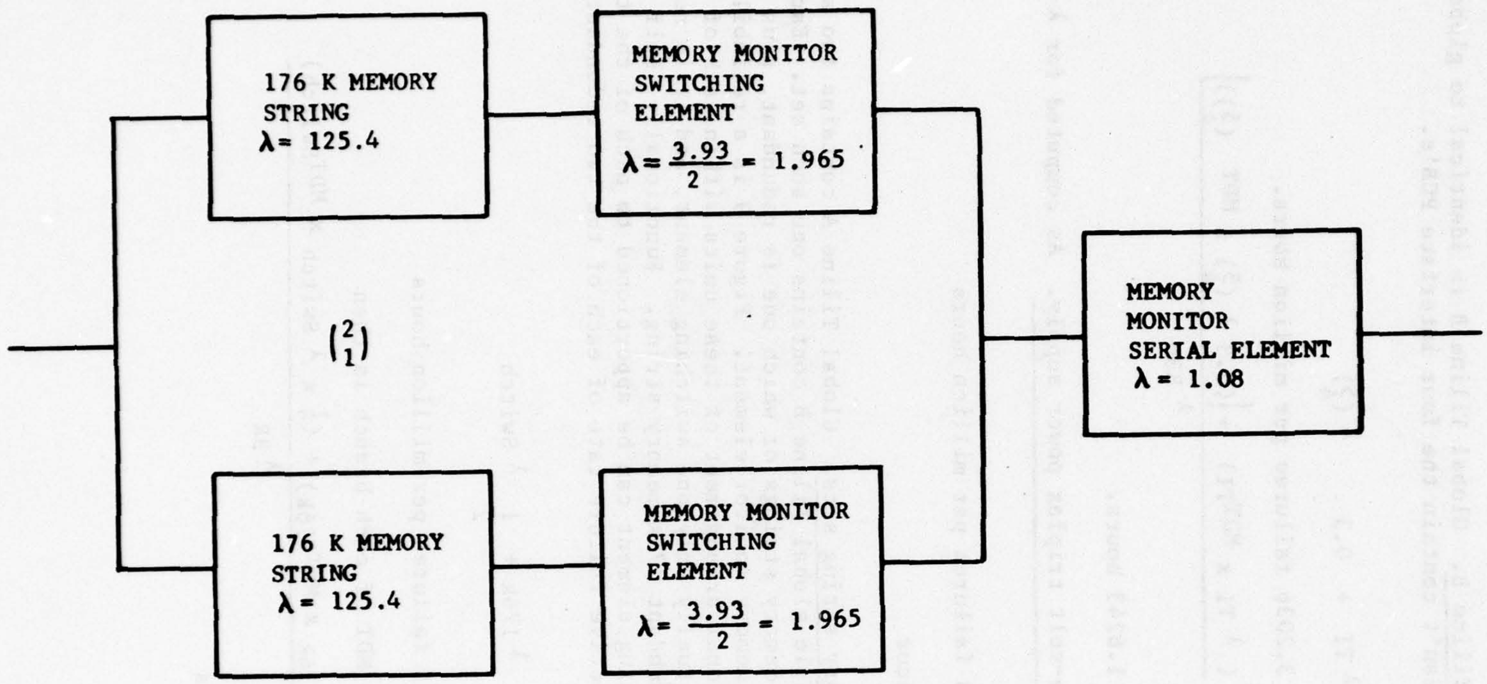
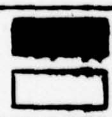


FIGURE 9. RELIABILITY DIAGRAM OF MEMORY AND MONITOR ELEMENTS IN EACH MEMORY STRING SET

As these memory strings are attached to the critical global Tilines, the 720-hour maintenance philosophy applies; hence, the state diagram technique will be used to determine the effective failure rate ($\lambda\binom{2}{1}$) of the two redundant branches. This is shown in table 11.

TABLE 11. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE OF GLOBAL MEMORY REDUNDANT BRANCHES

		Probability		Failure Mode Information		
State	Configuration	Formula	Numerical Value	λ	Failure Rate	Prob. x Fail. Rate
1		$P_2 = e^{-u}$	$P_2 = .83243045$	-	-	-
2		$P_1 = Ue^{-u}$	$P_1 = .15267241$	λ_{BR}	$127.365(10^{-6})$	$19.445(10^{-6})$
	Total		.98510286			$19.445(10^{-6})$

Where U = .1834056

Then $\lambda\binom{2}{1} = \frac{19.445}{.98510286} = 19.739$ failures/10^6 hours

The Einhorn equation is used to determine the effective MDT of the two redundant branches. This is:

$MDT_{\binom{2}{1}} = \frac{MDT_{BR}}{n - r + 1}$ where n = 2 (available units) and r = 1 (required units)

$MDT_{\binom{2}{1}} = 1$ hour

With the serial element added to the $\binom{2}{1}$ branch, the effective failure rate and MDT of one memory string set becomes:

$$\lambda_{SET} = \lambda\binom{2}{1} + \lambda_{Serial}$$

$$= 20.819 \text{ failures per million hours}$$

$$MDT_{SET} = \frac{\left[\lambda\binom{2}{1} \times MDT\binom{2}{1}\right] + \left[\lambda_{Serial} \times MDT_{Serial}\right]}{\lambda_{B3d}}$$

$$= 1.0519 \text{ hour}$$

Since there is a total of three memory string sets in global A and B Tilines, then

$$\lambda_{B3d} = 3x\,\lambda_{SET} = 62.457 \text{ failures per million hours}$$

$$MDT_{B3d} = MDT_{SET} = 1.0519 \text{ hour}$$

Global memory group summation. The effective failure rate and MDT of the global memory group are as follows:

$$\lambda_{B3} = \lambda_{B3a} + \lambda_{B3b} + 2\,\lambda_{B3c} + \lambda_{B3d}$$

$$= 159.684 \text{ failures per million hours}$$

$$MDT_{B3} = \frac{(\lambda_{B3a} \times MDT_{B3a}) + (\lambda_{B3b} \times MDT_{B3b}) + (2\,\lambda_{B3c} \times MDT_{B3c}) + (\lambda_{B3d} \times MDT_{B3d})}{\lambda_{B3}}$$

$$= 1.6 \text{ hours}$$

Computer Section Summation. The effective failure rate and MDT of the computer section are as follows:

$$\lambda_{B} = \lambda_{B1} + \lambda_{B2} + \lambda_{B3}$$

$$= 454.782 \text{ failures per million hours}$$

$$MDT_{B} = \frac{(\lambda_{B1} \times MDT_{B1}) + (\lambda_{B2} \times MDT_{B2}) + (\lambda_{B3} \times MDT_{B3})}{\lambda_{B}}$$

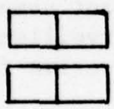
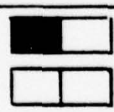
$$= 1.3 \text{ hours}$$

Communications section. The communications section reliability model, shown in figure 4, consists of four groups: the communications group, the communications interface group, and the surveillance and CIDIN groups. The communications group includes the three computers (surveillance, CIDIN, and spare) which are located within the communications Tiline. All this is contained in one equipment rack (the communications console) and is listed as such in the summary printout (table 7).

The remaining three groups consist of those elements in the data path between the communications interface Tiline and the external equipments with which the DABS communicates. The communications interface Tiline, which contains the communications interface PCB's for both the CIDIN and surveillance groups, is contained in one equipment rack (the communications interface console). The modems and link switches which transfer the data to and from the external equipments are located in two additional equipment racks. These remaining three groups are therefore listed as a single entry in table 7 (communications I/F console including modems).

The communications Tiline and communications interface Tiline are connected by two coupler pairs, one of which is redundant. Since both of these Tilines are critical to system operation, the 720-hour maintenance philosophy applies in determining the equivalent failure rate of this $\binom{2}{1}$ redundant coupler pair combination; therefore, the state diagram technique is used. This is shown in table 12.

TABLE 12. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE DETERMINATION OF $\binom{2}{1}$ REDUNDANT COUPLER PAIR COMBINATION

		Probability		Failure Mode Information		
State	Configuration	Formula	Numerical Value	λ	Failure Rate	Prob. x Fail. Rate
1		$P_2 = e^{-u}$	.97553621	-	-	-
2		$P_1 = Ue^{-u}$	.02416208	λ_c	$1.72(10^{-5})$	$.41559(10^{-6})$
Total			.99969829			$.41559(10^{-6})$

Where U = 0.024768 and

$\lambda_c = 1.72\text{x}10^{-5}$

$\lambda_{\binom{2}{1}\text{ Coupler}}$ = 0.416 failures per million hours

The MDT determined by the Einhorn equation is:

$$MDT_{\binom{2}{1}} = \frac{D}{2} = 1 \text{ hour}$$

This equivalent failure rate is apportioned equally between the communications Tiline and the communications interface Tiline.

Communications Console. This includes the communications Tiline, together with its 5-volt triplex power supply and the three computers which it contains. As one of these computers is a spare, the computers comprise a $\binom{3}{2}$ redundant combination.

Communications Tiline. The communications Tiline contains 2 of the 10 individual couplers comprising the $\binom{5}{4}$ coupler pair combination and 2 of the 4 couplers comprising the $\binom{2}{1}$ coupler pair combination. Therefore,

$$\lambda_{C1a} = \lambda_{TI} + 0.2\,\lambda\binom{5}{4} + 0.5\,\lambda\binom{2}{1}$$

$$= 3.0104 \text{ failures per million per million hours}$$

$$MDC_{C1a} = \frac{(\lambda_{TI} \times MDT_{TI}) + \left[0.2\,\lambda\binom{5}{4} \times MDT\binom{5}{4}\right] + \left[0.5\binom{2}{1} \times MDT\binom{2}{1}\right]}{\lambda_{C1a}}$$

$$MDT_{C1a} = 1.6643 \text{ hours}$$

Triplex power supply. As computed for λ B1b on page 36,

$$\lambda_{C1b} = .93 \text{ failures per million hours}$$

$$MDC_{C1b} = 1 \text{ hour}$$

$\binom{3}{2}$ Computer combination. This contains the redundant computer that can serve as a spare for either the ensemble group or the surveillance or CIDIN computers as required. As worked out in appendix A, the effective failure rates (λ_{C1c}) and MDT_{C1c} are, respectively:

$$\lambda_{C1c} = 139.37 \text{ failures per million hours}$$

and $$MDT_{C1c} = 1 \text{ hour}$$

Communications console summation. The effective failure rate and MDT of the communications console portion of the communications section are as follows:

$$\lambda_{C1} = \lambda_{C1a} + \lambda_{C1b} + \lambda_{C1c}$$

$$= 143.310 \text{ failures per million hours}$$

$$MDT_{C1} = \frac{(\lambda_{C1a} \times MDT_{C1a}) + (\lambda_{C1b} \times MDT_{C1b}) + (\lambda_{C1c} \times MDT_{C1c}}{\lambda_{C1}}$$

$$= 1.0 \text{ hour (rounded to nearest tenth)}$$

Communications Interface Console. With regard to reliability, the communications interface console contains the communications interface Tiline, including its power supplies and all communications elements between this

Tiline and the external equipments with which the DABS communicates. This consists of the following elements or subgroups:

(a) Communications Interface Tiline

(b) +5-Volt Triplex Power Supply

(c) $\pm$12-Volt Duplex Power Supplies

(d) $\binom{3}{2}$ Surveillance Transmit Plus Modems

(e) Link Switch (Surveillance)

(f) Primary Radar Interface

(g) Surveillance Receiver

(h) $\binom{7}{6}$ CIDIN Interface Plus Modems

(i) Link Switch (Communications)

Communications interface Tiline. The communications interface Tiline includes the other half of the $\binom{2}{1}$ coupler pair combination. Therefore:

$$\lambda_{C2a} = \lambda_{TI} + 0.5 \ \lambda_{\binom{2}{1}}$$

$$= 2.208 \text{ failures per million hours}$$

$$MDC_{C2a} = \frac{(\lambda_{TL} \times MDT_{TL}) + \left[0.5\lambda_{\binom{2}{1}} \times MDT_{\binom{2}{1}}\right]}{\lambda_{C2a}}$$

$$= 1.9058 \text{ hours}$$

+5-volt triplex power supply. As computed for λ_{B1b} on page 36,

$$\lambda_{C2b} = 0.93 \text{ failures per million hours}$$

$$MDB_{C2b} = 1 \text{ hour}$$

$\pm$12-volt duplex power supplies. These are actually two duplexes in series: a $\binom{2}{1}$ plus 12-volt combination and a $\binom{2}{1}$ minus 12-volt combination. As these four power supplies are identical, the following Einhorn equations are used:

$$\lambda_{C2c} = 2 x 2 \ (\lambda_{ps})^2 \times D_{ps}, \text{ where } \lambda_{ps} \text{ and } D_{ps}$$

are the failure rate and MDT, respectively, of each 12-volt power supply. Then:

$$\lambda_{C2c} = 0.59 \text{ failures per million hours}$$

$$MDT_{C2c} = 1 \text{ hour}$$

(3) <u>Surveillance transmit plus modems</u>. The operation of this subgroup can be explained with the aid of figure 10. As seen in this diagram, three communications I/F PCB's plug into the communications interface Tiline. Each of these PCB's consists of a serial element and two channel elements (A and B). The data to or from each channel element are through a modem to the link switch.

System operation requires at least two A <u>and</u> B channel paths to be operational. Failure of a serial element causes loss of both associated A <u>and</u> B channel paths. Hence, failure of a serial element in one communications I/F PCB followed by a channel element or modem failure in another communications I/F PCB will cause loss of system operation. Failure of two channel A <u>or</u> channel B elements or modems will also cause loss of system operation.

The effective failure rate of the surveillance transmit combination is determined by means of the state diagram technique, which the operational states are represented by various combinations of serial elements, channel elements, and modems. In order to determine the probability of any operational state, the combination is broken down into three parts which we will designate as S, T, and M.

Parts S and T are the serial and channel elements, respectively, of the communications I/F PCB, which is attached to the communications I/F Tiline. Since this Tiline is critical to system operation, the 720-hour scheduled maintenance repair philosophy applies. Part M is the modem, which is repaired or replaced immediately upon failure.

The probability of each of the operational states is a function of the probabilities associated with the number of S, T, and M elements in the state. The state diagram for the equivalent failure rate is described in detail in appendix B. The summary, shown in table 13, shows that the effective failure rate of the surveillance transmit plus modems combination is 11.17 failures per million hours.

For the effective MDT calculation, the state diagram technique is also used. The summary, shown in table 14, shows that the effective MDT of the surveillance transmit combination is 1.0 hour. The probability of the modem (M) part is the same as that used in the effective failure rate calculations. The probabilities of the S and T parts, however, are the probabilities of these parts being operational at any time, rather than over a 720-hour period. The probability of a single S or T element being operational at any time is U/U + D, where U and D are the MTBF and MDT, respectively, of the element. Since $U = 1/\lambda$, P can also be expressed as:

$1/(1+\lambda D)$. Then $P_S = \dfrac{1}{1+\lambda_S D_S} = .9999777605$ and

$$P_T = \frac{1}{1+\lambda_T D_T} = .9999888801$$

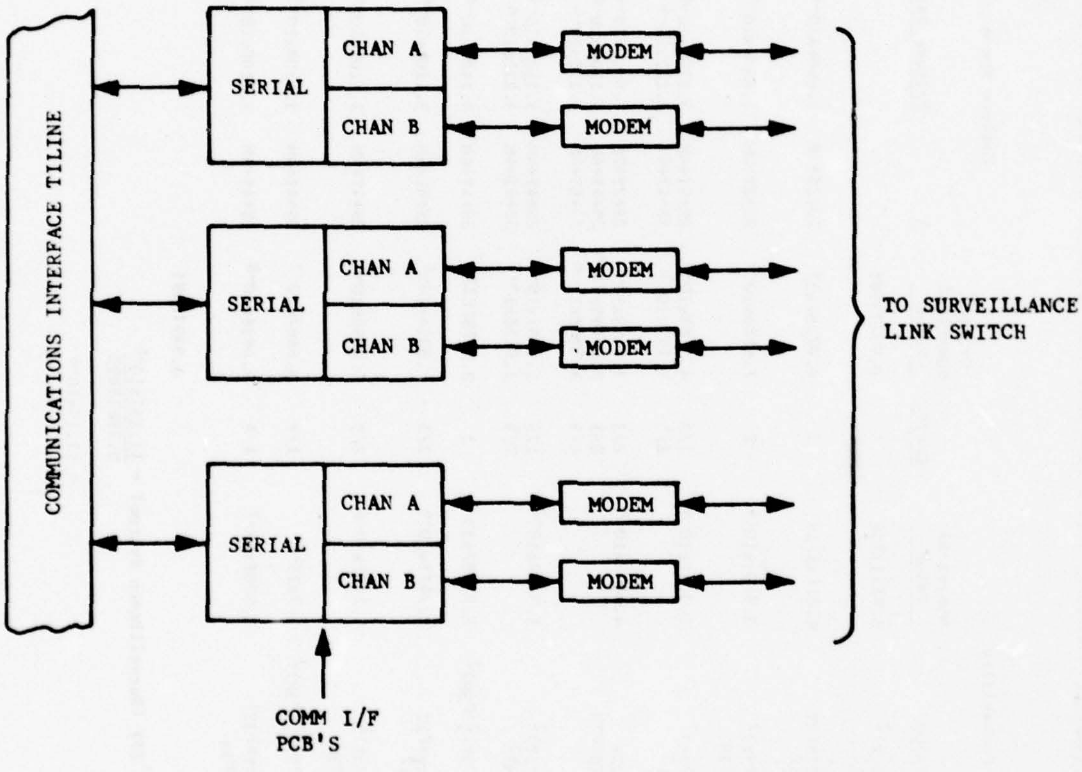


FIGURE 10. ($\frac{3}{2}$) SURVEILLANCE TRANSMIT AND MODEMS

TABLE 13. EQUIVALENT FAILURE RATE SUMMARY FOR SINGLE-CHANNEL SURVEILLANCE TRANSMIT COMBINATION

	Probability				Failure Modes		
State	Expression	Numerical Value	Coeff.	Overall Numerical Value	λ	Failure Rate	Prob. x Failure Rate
1	$P_{3S}x(P_{3T})^2$ $x(P_{3M})^2$	0.95233508	1	0.95233508	-	-	-
2	$P_{3S}xP_{2T}xP_{3T}$ $x(P_{3M})^2$	0.01143716	2	0.02287432	2S+2T+2M	$1.6666x10^{-4}$	$3.8122x10^{-6}$
3	$P_{3S}x(P_{3T})^2$ $xP_{2M}xP_{3M}$	$3.8093x10^{-4}$	2	$7.6186x10^{-4}$	2S+2T+2M	$1.6666x10^{-4}$	$1.2697x10^{-7}$
4	$P_{3S}x(P_{2T})^2$ $x(P_{3M})^2$	$1.3736x10^{-4}$	1/3 2/3	$4.5785x10^{-5}$ $9.157x10^{-5}$	2S+4T+4M 3S+4T+4M	$3.1108x10^{-4}$ $3.222x10^{-4}$	$1.4243x10^{-8}$ $2.9504x10^{-8}$
5	$P_{3S}+P_{2T}x$ $P_{3T}xP_{2M}xP_{3M}$	$4.5749x10^{-6}$	2/3 2/3 4/3	$3.0499x10^{-6}$ $3.04499x10^{-6}$ $6.0998x10^{-6}$	2S+2T+2M 2S+4T+4M 3S+4T+4M	$1.6666x10^{-4}$ $3.1108x10^{-4}$ $3.222x10^{-4}$	$5.083x10^{-10}$ $9.4876x10^{-10}$ $1.9654x10^{-9}$
6	$P_{3S}x(P_{3T})^2$ $x(P_{2M})^2$	$1.5237x10^{-7}$	1/3 2/3	$5.0791x10^{-8}$ $1.0158x10^{-7}$	2S+4T+4M 3S+4T+4M	$3.1108x10^{-4}$ $3.222x10^{-4}$	$1.58x10^{-11}$ $3.273x10^{-11}$
7	$P_{2S}x(P_{3T})^2_x(P_{3M})^2$	0.02287433	1	0.02287433	2S+4T+4M	$3.1108x10^{-4}$	$7.1157x10^{-6}$
8	$P_{2S}xP_{3T}xP_{2T}$ $x(P_{3M})^2$	$2.7471x10^{-4}$	2/3	$1.8314x10^{-4}$	2S+4T+4M	$3.1108x10^{-4}$	$5.6971x10^{-8}$
9	$P_{2S}x(P_{3T})^2$ $xP_{2M}xP_{3M}$	$9.1497x10^{-6}$	2/3	$6.0998x10^{-6}$	2S+4T+4M	$3.1108x10^{-4}$	$1.8975x10^{-9}$
10	$P_{2S}x(P_{2T})^2_x(P_{3M})^2$	$3.3x10^{-6}$	1/9	$3.6667x10^{-7}$	2S+4T+4M	$3.1108x10^{-4}$	1.1406x10-1-
11	$P_{2S}xP_{2T}xP_{3T}$ $xP_{2M}xP_{3M}$	$1.0988x10^{-7}$	4/9	$4.8838x10^{-8}$	2S+4T+4M	$3.1108x10^{-4}$	$1.5192x10^{-11}$
							$11.161x10^{-6}$
	Total			0.99918495			

$$\lambda_{EFF}\text{ (Surveillance System)} = \frac{11.161x10^{-6}}{0.99918495}$$

$$= 11.17x10^{-6}$$

TABLE 14. STATE SUMMARY FOR DETERMINATION OF MDT OF SINGLE-CHANNEL SURVEILLANCE TRANSMIT COMBINATION

	Probability				Failure Modes		
State	Expression	Numerical Value	Coeff.	Overall Numerical Value	λ	Failure Rate	Prob. x Failure Rate
1	$P_{3S}\times(P_{3T})^2 \times(P_{3M})^2$	0.9990670499	1	0.9990670499	-	-	-
2	$P_{3S}\times P_{2T}\times P_{3T} \times(P_{3M})^2$	3.332887679×10^{-5}	2	6.665775358×10^{-5}	2S+2T+2M	1.6666×10^{-4}	1.11092×10^{-8}
3	$P_{3S}\times(P_{3T})^2 \times P_{2M}\times P_{3M}$	3.9962682×10^{-4}	2	7.992536399×10^{-4}	2S+2T+2M	1.6666×10^{-4}	1.332036×10^{-7}
4	$P_{3S}\times(P_{2T})^2 \times(P_{3M})^2$	1.11185133×10^{-9}	1/3 2/3	3.7061711×10^{-10} 7.4123422×10^{-10}	2S+4T+4M 3S+4T+4M	3.1108×10^{-4} 3.222×10^{-4}	1.1529×10^{-13} 2.38826×10^{-13}
5	$P_{3S}\times P_{2T}\times P_{3T}\times P_{2M}\times P_{3M}$	1.33×10^{-8}	2/3 2/3 4/3	8.866666667×10^{-9} 8.866666667×10^{-9} 1.773333333×10^{-8}	2S+2T+2M 2S+4T+4M 3S+4T+4M	1.6666×10^{-4} 3.1108×10^{-4} 3.222×10^{-4}	1.4777×10^{-12} 2.75824×10^{-12} 5.71368×10^{-12}
6	$P_{3S}\times(P_{3T})^2 \times(P_{2M})^2$	1.599×10^{-7}	1/3 2/3	5.33×10^{-8} 1.066×10^{-7}	2S+4T+4M 3S+4T+4M	3.1108×10^{-4} 3.222×10^{-4}	1.65805×10^{-11} 3.43465×10^{-11}
7	$P_{2S}\times(P_{3T})^2\times(P_{3M})^2$	6.66578×10^{-5}	1	6.66578×10^{-5}	2S+4T+4M	3.1108×10^{-4}	2.0736×10^{-8}
8	$P_{2S}\times P_{3T}\times P_{2T} \times(P_{3M})^2$	2.2×10^{-9}	2/3	1.466666667×10^{-9}	2S+4T+4M	3.1108×10^{-4}	4.5525×10^{-13}
9	$P_{2S}\times(P_{3T})^2 \times P_{2M}\times P_{3M}$	2.6663×10^{-8}	2/3	1.777540095×10^{-8}	2S+4T+4M	3.1108×10^{-4}	5.5296×10^{-12}
10	$P_{2S}\times(P_{2T})^2\times(P_{3M})^2$	$7.418272073\times10^{-14}$	1/9	$8.242524525\times10^{-15}$	2S+4T+4M	3.1108×10^{-4}	2.56408×10^{-18}
11	$P_{2S}\times P_{2T}\times P_{3T} \times P_{2M}\times P_{3M}$	$8.894810639\times10^{-13}$	4/9	$3.953249173\times10^{-13}$	2S+4T+4M	3.1108×10^{-4}	1.22977×10^{-16}
		Total		0.9999998348			1.65116×10^{-7}
		1-Total		1.652×10^{-7}			

$$MDT_{EFF} = \frac{1 - \Sigma \text{ State Probabilities}}{\Sigma(\text{Prob. x Failure Rates})} = \frac{1.652\times10^{-7}}{1.65116\times10^{-7}} = 1 \text{ hour}$$

The probabilities of all three S and T elements being operational at any time are given by:

$$P_{3S} = P_S^3 = (.9999777605)^3 = .999933283$$

and $$P_{3T} = P_T^3 = (.9999888801)^3 = .9999666407$$

The probabilities of two S or T elements being operational at any time are given by:

$$P_{2S} = 3\ P_S^2\ (1-P_S) = 6.67155 \times 10^{-5}$$

and $$P_{2T} = 3\ P_T^2\ (1-P_T) = 3.33589 \times 10^{-5}$$

Link switch (surveillance). As shown in the element type summary of table 7:

$$\lambda_{C2e} = 3.15 \text{ failures per million hours}$$

$$MDT_{C2e} = 2 \text{ hours}$$

Primary radar interface. As shown in the element type summary of table 7:

$$\lambda_{C2f} = 3.36 \text{ failures per million hours}$$

$$MDT_{C2f} = 2 \text{ hours}$$

Surveillance receiver. This is actually a communications I/F PCB which consists of one serial and two channel elements. Then, from the element type summary of table 7:

$$\lambda_{C2g} = \lambda_{SER} + \lambda\ 2_{CHAN}$$

$$= 22.24 \text{ failures per million hours}$$

$$MDT_{C2g} = \frac{(\lambda_{SER} \times MDT_{SER}) + (2\ \lambda_{CHAN} \times MDT_{CHAN})}{\lambda_{C2g}}$$

$$= 2 \text{ hours}$$

$\binom{7}{6}$ CIDIN interface plus modems. The operation of this subgroup can be explained with the aid of figure 11. As seen in this diagram, there are seven paths from the communications I/F Tiline to the link switch. Each path consists of a communications I/F PCB (containing one serial and two channel elements) and a modem. Six of these seven paths are required for system operation.

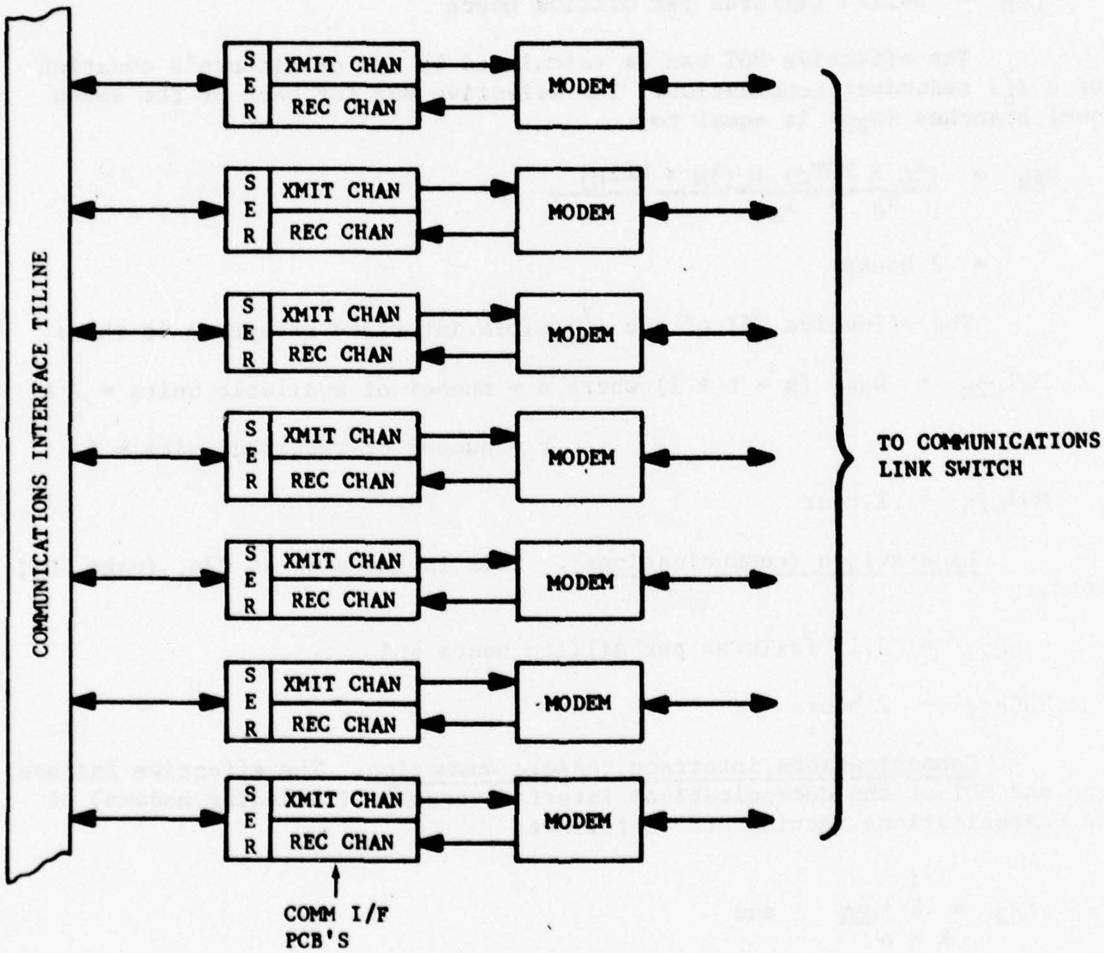


FIGURE 11. ($\frac{7}{6}$) CIDIN INTERFACE PLUS MODEMS

Since the communications I/F PCB's are plugged into the communications I/F Tiline, which is critical to system operation, the 720-hour repair philosophy of failed communication I/F PCB's applies. The modems are repaired or replaced immediately upon failure. Therefore, the effective failure rate will be determined by means of the state diagram technique shown in table 15.

The effective failure rate of the CIDIN interface subsystem is then:

λ_{C2h} = *54.175 failures per million hours*

The effective MDT can be calculated by use of Einhorn's equation for a $\binom{7}{6}$ redundant combination. The effective MDT for each of the seven equal branches (D_{BR}) is equal to:

$$D_{BR} = \frac{(\lambda_C \times MDT_C) + (\lambda_M \times MDT_M)}{\lambda_C + \lambda_M}$$

= 2 hours

The effective MDT of the $\binom{7}{6}$ CIDIN interface subsystem is then:

MDT_{C2h} = $D_{BR}/(n - r + 1)$ where n = number of available units = 7 &

r = number of required units = 6.

MDT_{C2h} = 1 hour

Link switch (communications). This is the same as C2e, (page 50); hence,

λ_{C2i} = 3.15 failures per million hours and

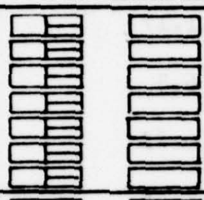
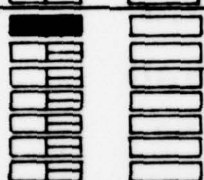
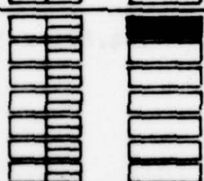
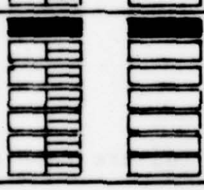
MDC_{C2i} = 2 hours

Communications interface console summation. The effective failure rate and MDT of the communications interface console (including modems) of the Communications Section are as follows:

$$\lambda_{C2} = \sum_{k=a}^{i} \lambda_{C2k} \quad \text{and}$$

$$MDT_{C2} = \frac{\sum_{k=a}^{i} (\lambda_{C2k} \times MDT_{C2k})}{\lambda_{C2}}$$

TABLE 15. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE DETERMINATION OF $\binom{7}{6}$ CIDIN INTERFACE COMBINATION

State	Configuration C M	Probability: Formula	Probability: Numerical Value	Failure Mode Information: λ	Failure Mode Information: Failure Rate	Failure Mode Information: Prob. x Failure Rate
1		$P_1 = P_{7c} x P_{7M}$	.89313023	-	-	-
2		$P_2 = P_{6c} x P_{7M}$	.10011061	$\lambda_{6c} + \lambda_{6M}$	5.3344x 10^{-4}	5.3403 x10^{-5}
3		$P_3 = P_{7C} x P_{6M}$	8.3359x 10^{-4}	$\lambda_{6c} + \lambda_{6M}$	5.3344x 10^{-4}	4.4467 x10^{-7}
4		$P_4 = \frac{P_{6c} x P_{6M}}{7}$	1.3348x 10^{-5}	$\lambda_{6c} + \lambda_{6M}$	5.3344x 10^{-4}	7.1204 x10^{-9}
Total			.99408778			53.855x10^{-6}

Where C stands for the communications I/F PCB and M stands for the modems.

$P_{7c} = e^{-u}$ where $U = .1120896$

$P_{7C} = .89396416,$

$P_{6c} = Ue^{-u} = .10020408$

$$P_M = \frac{1}{1 + \lambda_M D_M} = .99986668$$

$P_{7M} = (P_M)^7 = (.99986668)^7 = .99906716$

$P_{6M} = (P_M)^6 (1-P_M) = 9.3246 \times 10^{-4}$

$\lambda_{6C} = 6 \times 22.24 (10^{-6}) = 1.3344 \times 10^{-4}$

$\lambda_{6M} = 6 \times 66.67 (10^{-6}) = 4 \times 10^{-4}$

Thus:

λ_{C2a}	= 2.208	MDT_{C2a}	= 1.9058	$\lambda_{C2a} \times MDT_{C2a}$	= 4.208
λ_{C2b}	= 0.93	MDT_{C2b}	= 1.00	$\lambda_{C2b} \times MDT_{C2b}$	= 0.93
λ_{C2c}	= 0.59	MDT_{C2c}	= 1.00	$\lambda_{C2c} \times MDT_{C2c}$	= 0.59
λ_{C2d}	=11.17	MDT_{C2d}	= 1.00	$\lambda_{C2d} \times MDT_{C2d}$	= 11.17
λ_{C2e}	= 3.15	MDT_{C2e}	= 2.00	$\lambda_{C2e} \times MDT_{C2e}$	= 6.3
λ_{C2f}	= 3.36	MDT_{C2f}	= 2.00	$\lambda_{C2f} \times MDT_{C2f}$	= 6.72
λ_{C2g}	=22.24	MDT_{C2g}	= 2.00	$\lambda_{C2g} \times MDT_{C2g}$	= 44.48
λ_{C2h}	=54.175	MDT_{C2b}	= 1.00	$\lambda_{C2b} \times MDT_{C2h}$	= 54.175
λ_{C2i}	= 3.15	MDT_{C2i}	= 2.00	$\lambda_{C2i} \times MDT_{C2i}$	= 6.3

$$\sum_{k=a}^{i} (\lambda_{C2k} \times MDT_{C2k}) = 134.873 \times 10^{-6}$$

$$\sum_{k=a}^{i} \lambda_{C2k} = 100.973 \text{ failures per million hours} = \lambda_{C2}$$

$$MDT_{C2} = \frac{134.873}{100.973} = 1.3 \text{ hours (rounded to tenths)}$$

Communications Section Summary. The effective failure rate and MDT of the Communications Sections are as follows:

$$\lambda_C = \lambda_{C1} + \lambda_{C2}$$

$$= 244.283 \text{ failures per million hours}$$

$$MDT_C = \frac{(\lambda_{C1} \times MDT_{C1}) + (\lambda_{C2} \times MDT_{C2})}{\lambda_C}$$

$$= 1.1 \text{ hour}$$

SINGLE-CHANNEL SYSTEM SUMMARY. The overall system failure rate,

$$\lambda_{Sys} = \lambda_A + \lambda_B + \lambda_C$$

$$= 1291.921 \text{ failures per million hours}$$

The overall system MDT is:

$$MDT_{Sys} = \frac{(\lambda_A \times MDT_A) + (\lambda_B \times MDT_B) + (\lambda_C \times MDT_C)}{\lambda_{Sys}}$$

$$= 1.6 \text{ hours}$$

The system MTBF is the reciprocal of the system failure rate.

$$MTBF = 774 \text{ hours}$$

DUAL-CHANNEL SENSOR ANALYSIS. The reliability model for the theoretical dual-channel sensor is shown in figure 12. As seen in this figure, two strings of elements are duplicated in order to provide the 20,000-hour MTBF specified in the ER. One of these, the redundant I&P computer string, includes elements from the I&P and computer sections of the single-channel sensor. The other, the redundant communications string, includes certain elements of the communications section.

As in the single-channel sensor, certain redundant elements which are connected to critical Tilines would be left in the system upon failure until a convenient time for replacement occurs. The dual-channel sensor is predicated upon a daily replacement of such failed elements, the replacement to be accomplished during the hours of minimum workload.

A 6-hour minimum workload period will be assumed in this model, leaving the maximum time to replacement as 18 hours. As in the case of the single-channel model, the program for the dual-channel model will have the capability of varying this 18-hour maximum replacement time to any other desired value. Pertinent portions of this model will be discussed.

Redundant I&P/computer string. As seen in figure 12, the five interface PCB's are among the elements duplicated. Four of the five PCB's in each duplicated string are attached to one of the global Tilines (A and B). As the global Tilines are not duplicated, they are critical, since both are required. Hence, the 18-hour replacement philosophy applies to these four interface PCB's. The remaining interface PCB is attached to the ATCRBS Tiline which, as seen in figure 12, is duplicated. Should this PCB fail, the ATCRBS Tiline can be deenergized, and the PCB replaced immediately, since the ATCRBS Tiline in the redundant string is still operational.

Since each of the two strings contain elements which can be replaced immediately and elements for which the 18-hour replacement philosophy applies, the state diagram technique must be used to determine the effective failure rate of the redundant I&P/computer strings. Let A, therefore, represent the elements in each of the two I&P/computer strings for which the immediate replacement philosophy applies. This includes the transmitter, receiver, processor, ATCRBS Tiline and power supply, one ATCRBS computer, one ATCRBS interface PCB, and the WWVB receiver. The total failure rate, λ_A, for these elements is:

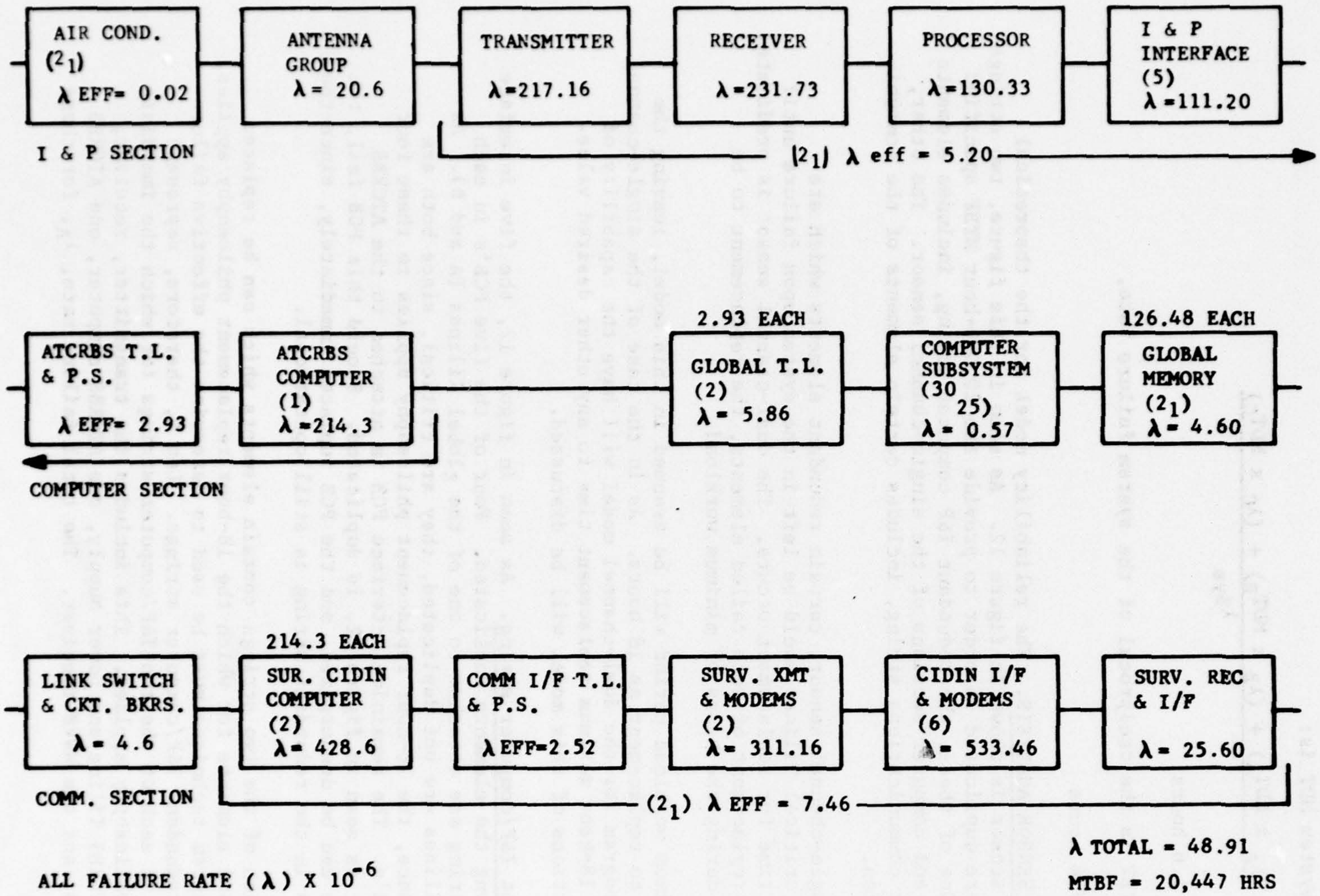


FIGURE 12. DABS SENSOR RELIABILITY MODEL--DUAL CHANNEL

Element	Failure Rate per 10^6 Hours	MDT (hours)
Transmitter	217.16	2.00
Receiver	231.73	2.00
Processor	130.33	2.00
ATCRBS Interface PCB	22.24	2.00
WWVB Receiver	0.00	0.00
ATCRBS Tiline	2.00	2.00
+5-Volt Triplex PS	0.93	1.00
ATCRBS Computer	214.3	2.00

$$\lambda_A = 818.69 \text{ failures per million hours}$$

$$U_A = 1/\lambda_A = 1221.4636 \text{ hours}$$

$$D_A = 1.9989 \text{ hours}$$

The probability of two sets of A elements being operational at any time is:

$$P_{2A} = \left[\frac{1221\text{-}4636}{1221.4636 + 1.9989}\right]^2 = .99673506$$

The probability of one set of A elements at any time is:

$$P_{1A} = 2\left[\frac{1221.4636}{1223.4625}\right]\left[\frac{1.9989}{1223.4625}\right] = .00326227$$

Let B represent the four interface PCB's for which the 18-hour-per-day replacement philosophy applies. The combined failure rate (λ_B) of these four PCB's is:

$$\lambda_B = 4 \times 22.24\ (10^{-6}) = 88.96\ (10^{-6})$$

Then the MTBF of these four PCB's, $U_B = \frac{1}{\lambda_B} = 11{,}241$ hours

The probability of two sets of B elements being operational at any instant throughout a 24-hour period is given by:

$$P_{2B} = \frac{18e^{-u}}{24} + \frac{6}{24}\left[\frac{UB}{U_B + D_B}\right] \quad \text{where } U = 18 \times 2 \times 88.96\ (10^{-6}) = 3.2026\ (10^{-3}) \text{ and}$$

D_B is the MDT of the four PCB boards = 2 hours. This expression comes about because during 18 hours of the day, the B elements are governed by the 18-hour repair philosophy, and the remaining 6 hours represent minimum work-load time during which the critical Tiline can be deenergized and replacements made immediately.

$$\text{Then } P_{2B} = \frac{18}{24} e^{-3.2026\,(10^{-3})} + \frac{6}{24}\left(\frac{11241}{11243}\right)^2 = .997513$$

$$\text{and } P_{1B} = \frac{18}{24} Ue^{-u} + \frac{6}{24}(2)\frac{(11241)}{(11243)}\frac{(\ 2\ )}{(11243)} = .0024832$$

The state diagram probabilities for effective failure rates are as follows:

P_{2A} = .99673506

P_{1A} = .00326227

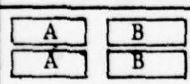
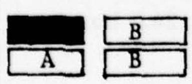
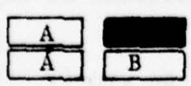
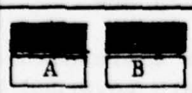
P_{2B} = .997513

P_{1B} = .0024832

$\lambda_{(1A + 1B)} = (818.69 + 88.96) \times 10^{-6} = 9.0765 \times 10^{-4}$

The state diagram is shown in table 16.

TABLE 16. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE DETERMINATION OF REDUNDANT I&P/COMPUTER STRING IN DUAL-CHANNEL SENSOR

State	Configuration	Probability: Formula	Probability: Numerical Value	Failure Mode Information: λ	Failure Mode Information: Failure Rate	Failure Mode Information: Prob. x Failure Rate
1		$P_{2A} x P_{2B}$	.99425618	-	-	-
2		$P_{1A} x P_{2B}$	.00325416	1A+1B	$9.0765(10^{-4})$	$2.9536x10^{-6}$
3		$P_{2A} x P_{1B}$	.00247509	1A+1B	$9.0765(10^{-4})$	$2.2465x10^{-6}$
4		$\frac{P_{1A} x P_{1B}}{2}$	$4.0504(10^{-6})$	1A+1B	$9.0765(10^{-4})$	$3.6764x10^{-9}$
	Total		.99998948			$5.2038x10^{-6}$

$$\lambda_{EFF}\ (I\&P/Comp) = \frac{5.2038\times10^{-6}}{.99998948} = 5.2038 \text{ failures per million hours}$$

MDT_{EFF} (I&P/Comp) = 1 hour (by Einhorn)

Ensemble group. The effective failure rate for the ensemble group is determined by the state diagram technique using an 18-hour maximum replacement rate and a 6-hour direct replacement rate for the global couplers (part G) of each ensemble and also for the two extra computers (part $\bar{C}$) attached to the ATCRBS Tiline. This works out to an effective failure rate λ ENS of 0.57 failures per million hours. The effective MDT is 0.8 hour.

Global memory. This, likewise, is worked out in similar fashion to the $\binom{2}{1}$ memory string sets discussed in part B3d of the single-channel sensor, substituting the 18-hour maximum and 6-hour direct replacement rates for the 720-hour replacement rate for the redundant 176k memory strings. This gives an effective failure rate of 1.532 failures per million hours for each of the three sets, or 4.596 failures per million hours for all three sets. The effective MDT is the same as that for the single-channel sensor = 1.0519 hour.

Redundant communications string. The effective failure rate for this redundant string is derived in a similar manner to that for the redundant I&P/computer string. Let C represent the elements in each of the two strings for which the *immediate replacement philosophy applies.* This is as follows:

Element	Failure Rate/10^6 Hours	MDT (hours)
Two Computers	428.60	2.0
Communications I/F Tiline	2.00	2.0
+5-Volt Triplex PS	0.93	1.0
±12-Volt Duplex PS	0.59	1.0
Eight Communications I/F Serials	88.96	2.0
16 Communications I/F Channels	88.96	2.0
10 Modems	666.70	2.0
Surveillance Receiver	22.24	2.0
Primary Radar Interface	3.36	2.0

λ_c = 1302.34 failures per million hours

$U_C = 1/\lambda_c$ 767.84864 hours

D_C = 1.9988 hours

P_{2C} = .99481402

P_{1C} = .00517923

Let D represent the coupler pair connecting each string to the global Tilines. Since each member of the pair attaches to a critical Tiline, the 18-hour replacement philosophy applies. Hence,

$\lambda_D = 17.2 \times 10^{-6}$, $U_D = 58139.533$, $D_D = 2$

$$P_{2D} = \frac{18}{24} e^{-u} + \frac{6}{24} \left[\frac{58139.535}{58141.535}\right]^2 \quad \text{where } U = 2 \times 17.2 \; (10^{-6}) \times 18$$

$$= 6.192 \; (10^{-4})$$

$P_{2D} = .99351854$ and

$$P_{1D} = \frac{18}{24} Ue^{-u} + \frac{6}{24} (2) \left[\frac{58139.535}{58141.535}\right] \left[\frac{2}{58141.535}\right]$$

$P_{1D} = .00048131$

$\lambda(1C + 1D) = (1302.34 + 17.2) \times 10^{-6} = 1319.54 \times 10^{-6}$

Applying the state diagram technique, shown in table 17,

TABLE 17. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE DETERMINATION OF REDUNDANT COMMUNICATIONS STRING IN DUAL-CHANNEL SENSOR

State	Configuration	Probability			Failure Mode Information	
		Formula	Numerical Value	λ	Failure Rate	Prob. x Failure Rate
1	C D / C D	$P_{2C} x P_{2D}$	.99433506	-	-	-
2	D / C D	$P_{1C} x P_{2D}$	.00517674	1C+1D	1319.54×10^{-6}	6.8309×10^{-6}
3	C / C D	$P_{2C} x P_{1D}$	.00047881	1C+1D	1319.54×10^{-6}	6.3181×10^{-7}
4	C D	$\frac{P_{1C} x P_{1D}}{2}$	1.2464×10^{-6}	1C+1D	1319.54×10^{-6}	1.6447×10^{-9}
	Total		.99999186			7.4644×10^{-6}

λ_{EFF} (Communications String) = 7.46 failures per million hour

MDT_{EFF} (Communications String) = 1 hour (by Einhorn)

DUAL-CHANNEL MTBF AND MDT SUMMATION. The overall failure rate, MTBF, and MDT of the dual-channel sensor are calculated as follows:

Element	Failure Rate/10^6 Hours	MDT (hours)
Air-Conditioners	0.02	1.0
Antenna Group	20.6	2.0
Redundant I&P/Computer String	5.20	1.0
Global Tilines	5.86	2.0
Ensemble Group	0.571	0.8
Global Memory Sets	4.596	1.0519
Link Switch and Circuit Breakers	4.6	2.0
Redundant Communications String	7.46	1.0

Σ Failure Rates = 48.907 failures per million hours

Σ(Failure Rate x MDT) = 80.091×10^{-6}

$$MDT = \frac{\Sigma(\text{Failure Rate x MDT})}{\Sigma \text{Failure Rates}} = 1.6 \text{ hours}$$

$$MTBF = \frac{1}{\Sigma \text{Failure Rates}} = 20{,}447 \text{ hours}$$

MAXIMUM CORRECTIVE MAINTENANCE TIMES. These values can be computed for each of the 20 element types by using as inputs the individual downtimes taken from the element status time summary, part 1 (table 3). These will be applied to the calculator, which will be programed with the necessary statistical algorithms to produce the 90th percentile of the maximum corrective maintenance time for each element type. These, in turn, can be used as inputs to obtain the 90th percentile of the maximum corrective maintenance time for the single and dual-channel sensors, using the mathematical models previously discussed.

SUMMARY

The main objective of the reliability and maintainability evaluation is the identification of weak points and problem areas in the system design. The three program outputs of the ARAP should provide significant aids toward meeting this objective. The status summaries provide a continuous running history of each of the 200+ DABS elements in each sensor, including periods of downtime caused by corrective maintenance. A comprehensive failure history is also provided for each element by the hardware failure summary, while the part failure summary provides information concerning analysis and disposition of the parts concerned for each failure.

The calculator printout provides further information on element type failure rates and MDT's. The effective failure rates and MDT's of the various sections and subsections are also provided. Finally, the overall system failure rate, MTBF, and MDT are provided for both single- and dual-channel sensors.

The calculator program has the capability of varying the maximum time to replacement of redundant PCB's plugged into critical Tilines. The effect of this variation upon subsection, section, and system failure rates can be very quickly observed, since all that is required is to key in the new MAXIMUM TIME TO REPLACEMENT OF FAILED PCB's. Element type data need not be reentered, since this is retained in the calculator memory. Hence, the effect upon the overall system MTBF of changing the maximum time to replacement from 1 month (720 hours) for the single-channel or 18 hours for the dual-channel sensors can be quickly and easily ascertained.

APPENDIX A

STATE DIAGRAM TECHNIQUE FOR DETERMINING EQUIVALENT FAILURE RATE AND MDT OF THE $\binom{30}{26}$ DABS ENSEMBLE GROUP AND THE $\binom{3}{2}$ COMMUNICATIONS COMPUTERS COMPOSITE

Since the $\binom{3}{2}$ communications computers and the $\binom{30}{26}$ ensemble group are not independent, the effective failure rate of the two redundant combinations considered as one composite entity must be determined using the state diagram technique. This composite failure rate is then apportioned between the two combinations in accordance with the appropriate states of the state diagrams.

The $\binom{30}{26}$ ensemble group consists of seven ensembles, each of which contains four computers. Two additional computers used with the ensemble group are physically attached to the ATCRBS Tiline. Each of the seven ensemble Tilines communicates with each global memory through a coupler pair. Thus, four couplers are associated with each of the seven ensembles. Failure of any one of these four couplers will cause loss of that ensemble.

For purposes of determining the probabilities of the various operational states of the composite, each of the seven ensembles is divided into three parts: G, E, and C. Part G consists of the two couplers located in the global Tilines. Part E consists of the ensemble Tiline together with its two couplers and the +5-volt triplex power supply. Part C consists of the four computers.

The two computers attached to the ATCRBS Tiline will be considered the fourth part of the composite (part $\bar{c}$), while the three communications computers will be considered the fifth part (part $\hat{c}$).

The composite has many operational states consisting of 6 or 7 part G's, 6 or 7 part E's, 23 to 28 part C's, 0 to 2 part $\bar{c}$'s, and 2 or 3 part $\hat{c}$'s. Table A-1 shows the 30 most significant states, each of which has a state probability of at least $1x10^{-6}$. Each of the five parts which comprise the probabilities of each of these 30 states is described below:

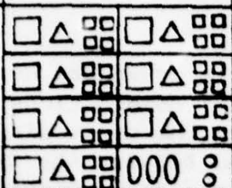
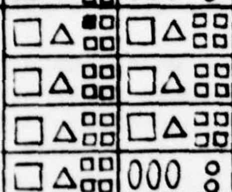
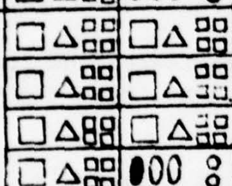
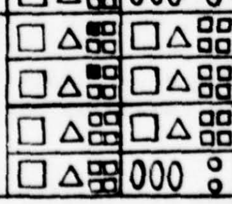
1. Part G has a 720-hour maintenance philosophy; therefore, the probability of seven part G's being available for 720 hours is $P_{7G} = e^{-U}$, where U = 7x720x G, where λG is the failure rate of the two couplers comprising part G. $\lambda G = 2x8.6(10^{-6}) = 1.72(10^{-5})$; therefore U = .086688 and P_{7G} = .91696314. The failure of one of these global couplers would leave six remaining part G's, the probability, P_{6G}, of which is Ue^{-U} or .0794897.

2. Since part E is corrected immediately upon failure, the probability of one of these parts being available at any given time is $P_E = \dfrac{U_E}{U_E + D_E}$ where U_E and D_E are the MTBF and MDT, respectively, of the part. Since $U_E = 1/\lambda_E$, P_E can also be expressed as $\dfrac{1}{1 + \lambda_E D_E}$,

where $\lambda_E = \lambda_{Tiline} + \lambda_{couplers} \times \lambda_{triplex\ PS}$

$\lambda_{triplex\ PS} = 0.93 \times 10^{-6}$, as per B1b of the text.

TABLE A-1. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE DETERMINATION OF ENSEMBLE/COMMUNICATIONS COMPUTER COMPOSITE

State	Configuration	Probability	Failure Modes		
			λ	Failure Rate	Prob. x Fail. Rate
33		$P_{33} = P_{7G} \times P_{7E} \times P_{28c} \times P_{2\bar{c}} \times P_{3\hat{c}}$ = .41876388	–	–	–
32A		$P_{32A} = P_{7G} \times P_{7E} \times P_{27c} \times P_{2\bar{c}} \times P_{3\hat{c}}$ = .00502558	–	–	–
32B		$P_{32B} = P_{7G} \times P_{7E} \times P_{28c} \times P_{1\bar{c}} \times P_{3\hat{c}}$ = .12922718	–	–	–
32C		$P_{32c} = P_{7G} \times P_{7E} \times P_{28c}\ P_{2\bar{c}} \times P_{2\hat{c}}$ = .19384078	$2\hat{c}$	4.286×10^{-4}	8.3081×10^{-5}
31A		$P_{31A} = \frac{1}{9} \times P_{7G} \times P_{7E} \times P_{26c} \times P_{2\bar{c}} \times P_{3\hat{c}} = 3.231 \times 10^{-6}$	6G + 6E	2.2398×10^{-4}	7.2366×10^{-10}
31B		$P_{31B} = 8/9 \times P_{7G} \times P_{7E} \times P_{26c} \times P_{2\bar{c}} \times P_{3\hat{c}} = 2.5847 \times 10^{-5}$	5G + 5E	1.8665×10^{-4}	4.8244×10^{-9}
SUBTOTAL		.74688642			8.3086×10^{-5}
CUMULATIVE TOTAL		.74688642			8.3086×10^{-5}

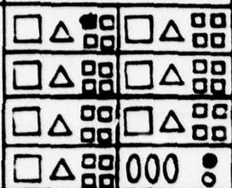
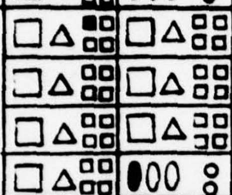
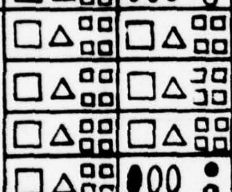
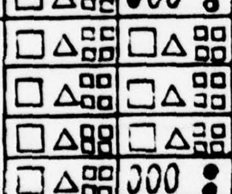
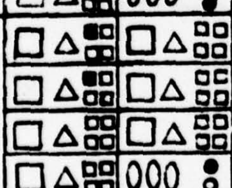
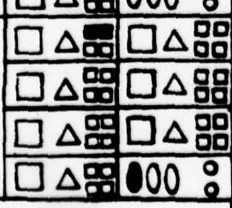
LEGEND

□ = G   ○ = $\bar{c}$

△ = E   0 = $\hat{c}$

▫ = C

TABLE A-1. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE DETERMINATION OF ENSEMBLE/COMMUNICATIONS COMPUTER COMPOSITE (Continued)

State	Configuration	Probability	Failure Modes		
			λ	Failure Rate	Prob. x Fail. Rate
31C		$P_{31c} = P_{7G} \times P_{7E} \times P_{27c} \times P_{1\bar{c}} \times P_{3\hat{c}} = .00155083$	6G + 6E	2.2398×10^{-4}	3.4735×10^{-7}
31D		$P_{31D} = P_{7G} \times P_{7E} \times P_{27c} \times P_{2\bar{c}} \times P_{2\hat{c}} = .00232624$	6G + 6E $2\hat{c}$	2.2398×10^{-4} 4.286×10^{-4}	1.5181×10^{-6}
31E		$P_{31E} \times P_{7G} \times P_{7E} \times P_{28G} \times P_{1\bar{c}} \times P_{2\hat{c}} = .0598177$	7G +7E $2\hat{c}$	2.6131×10^{-4} 4.286×10^{-4}	4.1269×10^{-5}
31F		$P_{31F} = P_{7G} \times P_{7E} \times P_{28c} \times P_{0\bar{c}} \times P_{3\hat{c}} = .02215879$	7G + 7E	2.6131×10^{-4}	5.7903×10^{-6}
30A		$P_{30A} = 8/9 \times P_{7G} \times P_{7E} \times P_{26c} \times P_{1\bar{c}} \times P_{3\hat{c}} = 7.9762 \times 10^{-6}$	7G + 7E	2.6131×10^{-4}	2.0843×10^{-9}
30B		$P_{30B} = \frac{1}{9} \times P_{7G} \times P_{7E} \times P_{26c} \times P_{2\bar{c}} \times P_{2\hat{c}} = 1.4955 \times 10^{-6}$	6G + 6E $2\hat{c}$	2.2398×10^{-4} 4.286×10^{-4}	9.7596×10^{-10}
SUBTOTAL		.08586303			4.8928×10^{-5}
CUMULATIVE TOTAL		.83274947			1.3201×10^{-4}

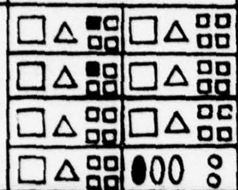
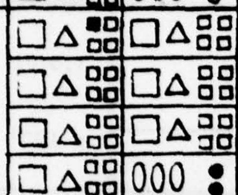
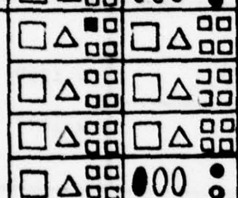
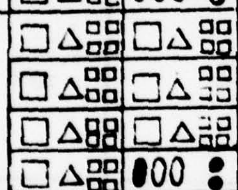
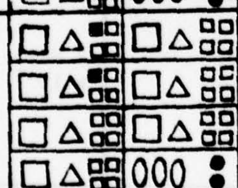
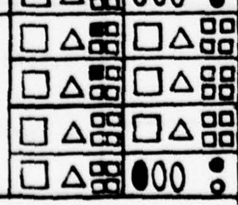
LEGEND

□ = G   o = $\bar{c}$

△ = E

▫ = C   0 = $\hat{c}$

TABLE A-1. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE DETERMINATION OF ENSEMBLE/COMMUNICATIONS COMPUTER COMPOSITE (Continued)

State	Configuration	Probability	Failure Modes: λ	Failure Modes: Failure Rate	Failure Modes: Prob. x Fail. Rate
30C		$P_{30c} = 8/9 \times P_{7G} \times P_{7E} \times P_{26c} \times P_{2\bar{c}} \times P_{2\hat{c}} = 1.1964 \times 10^{-5}$	7G + 7E $2\hat{c}$	2.6131×10^{-4} 4.286×10^{-4}	8.2543×10^{-9}
30D		$P_{30D} = P_{7G} \times P_{7E} \times P_{27c} \times P_{0\bar{c}} \times P_{3\hat{c}} = 2.6592 \times 10^{-4}$	7G + 7E	2.6131×10^{-4}	6.9488×10^{-8}
30E		$P_{30E} = P_{7G} \times P_{7E} \times P_{27c} \times P_{1\bar{c}} \times P_{2\hat{c}} = 7.1786 \times 10^{-4}$	7G + 7E $2\hat{c}$	2.6131×10^{-4} 4.286×10^{-4}	4.9526×10^{-7}
30F		$P_{30F} = P_{7G} \times P_{7E} \times P_{28c} \times P_{0\bar{c}} \times P_{2\hat{c}} = .01025704$	7G + 7E $2\hat{c}$	2.6131×10^{-4} 4.286×10^{-4}	7.0764×10^{-6}
29A		$P_{29A} = \frac{8}{9} \times P_{7G} \times P_{7E} \times P_{26c} \times P_{0\bar{c}} \times P_{3\hat{c}} = 1.3677 \times 10^{-6}$	7G + 7E	2.6131×10^{-4}	3.5739×10^{-10}
29B		$P_{29B} = 8/9 \times P_{7G} \times P_{7E} \times P_{26c} \times P_{1\bar{c}} \times P_{2\hat{c}} = 3.6921 \times 10^{-6}$	7G + 7E $2\hat{c}$	2.6131×10^{-4} 4.286	2.5472×10^{-9}
SUBTOTAL		1.1258×10^{-2}			7.6498×10^{-6}
CUMULATIVE TOTAL		.84400732			1.3966×10^{-4}

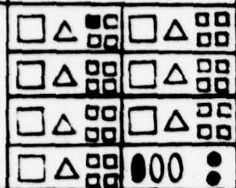
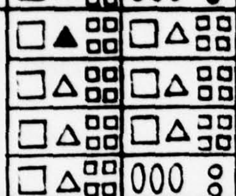
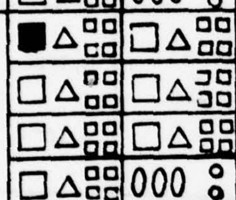
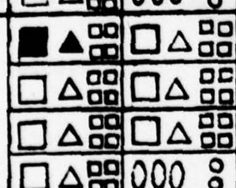
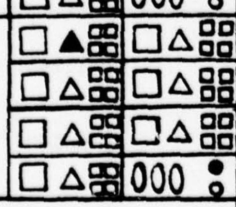
LEGEND

□ = G   o = $\bar{c}$

△ = E   0 = $\hat{c}$

▫ = C

TABLE A-1. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE DETERMINATION OF ENSEMBLE/COMMUNICATIONS COMPUTER COMPOSITE (Continued)

State	Configuration	Probability	Failure Modes		
			λ	Failure Rate	Prob. x Fail. Rate
29C		$P_{29c} = P_{7G} \times P_{7E} \times P_{27c} \times P_{0\bar{c}} \times P_{2\hat{c}} = 1.2309 \times 10^{-4}$	7G + 7E $2\hat{c}$	2.6131×10^{-4} 4.286×10^{-4}	8.4923 $\times 10^{-8}$
29D		$P_{29D} = P_{7G} \times P_{6E} \times P_{28c} \times P_{2\bar{c}} \times P_{3\hat{c}} = 1.1802 \times 10^{-4}$	6G + 6E	2.2398×10^{-4}	2.6433×10^{-8}
29E		$P_{29E} = P_{6G} \times P_{7E} \times P_{28c} \times P_{2\bar{c}} \times P_{3\hat{c}} = 3.6302 \times 10^{-2}$	6G + 6E	2.2398×10^{-4}	8.1309×10^{-6}
29F		$P_{29F} = \frac{1}{7} \times P_{6G} \times P_{7E} \times P_{27c} \times P_{2\bar{c}} \times P_{3\hat{c}} = 6.2236 \times 10^{-5}$	6G + 6E	2.2398×10^{-4}	1.394×10^{-8}
29G		$P_{29G} = \frac{1}{7} \times P_{6G} \times P_{6E} \times P_{28c} \times P_{2\bar{c}} \times P_{3\hat{c}} = 1.4615 \times 10^{-6}$	6G + 6E	2.2398×10^{-4}	3.2735×10^{-10}
28A		$P_{28A} = P_{7G} \times P_{6E} \times P_{28c} \times P_{1\bar{c}} \times P_{3\hat{c}} = 3.6419 \times 10^{-5}$	6G + 6E $24c + 1\bar{c} + 3\bar{c}$	2.2398×10^{-4} 6.0004×10^{-3}	2.2668 $\times 10^{-7}$
SUBTOTAL		3.6643×10^{-2}			8.4832×10^{-6}
CUMULATIVE TOTAL		.88065034			1.4815×10^{-4}

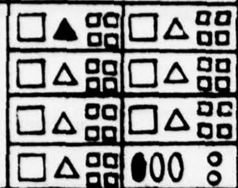
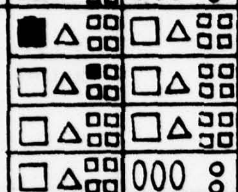
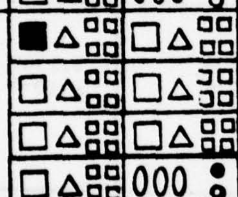
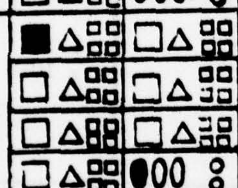
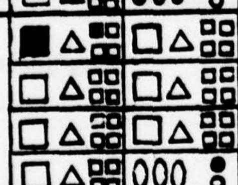
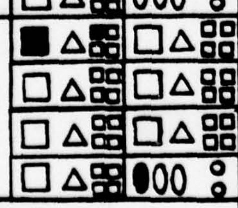
LEGEND

□ = G   ○ = $\bar{c}$

△ = E

▫ = C   0 = $\hat{c}$

TABLE A-1. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE DETERMINATION OF ENSEMBLE/COMMUNICATIONS COMPUTER COMPOSITE (Continued)

State	Configuration	Probability	Failure Modes λ	Failure Rate	Prob. x Fail. Rate
28B		$P_{28B} = P_{7G} \times P_{6E} \times P_{28c} \times P_{2\bar{c}} \times P_{2\hat{c}} = 5.4628 \times 10^{-5}$	6G + 6E	2.2398×10^{-4}	3.4003×10^{-7}
			$24c + 2\bar{c} + 2\hat{c}$	6.0004×10^{-3}	
28C		$P_{28c} = \frac{6}{7} \times P_{6G} \times P_{7E} \times P_{27c} \times P_{2\bar{c}} \times P_{3\hat{c}} = 3.7341 \times 10^{-4}$	6G + 6E	2.2398×10^{-4}	2.3243×10^{-6}
			$23c + 2\bar{c} + 3\hat{c}$	6.0004×10^{-3}	
28D		$P_{28D} = P_{6G} \times P_{7E} \times P_{28c} \times P_{1\bar{c}} \times P_{3\hat{c}} = 1.1202 \times 10^{-2}$	6G + 6E	2.2398×10^{-4}	6.9728×10^{-5}
			$24c + 1\bar{c} + 3\hat{c}$	6.0004×10^{-3}	
28E		$P_{28E} = P_{6G} \times P_{7E} \times P_{28c} \times P_{2\bar{c}} \times P_{2\hat{c}} = 1.6804 \times 10^{-2}$	6G + 6E	2.2398×10^{-4}	1.0459×10^{-4}
			$24c + 2\bar{c} + 2\hat{c}$	6.0004×10^{-3}	
28F		$P_{28F} = \frac{1}{7} \times P_{6G} \times P_{7E} \times P_{27c} \times P_{1\bar{c}} \times P_{3\hat{c}} = 1.9205 \times 10^{-5}$	6G + 6E	2.2398×10^{-4}	1.1954×10^{-7}
			$24c + 1\bar{c} + 3\hat{c}$	6.0004×10^{-3}	
28G		$P_{28G} = \frac{1}{7} \times P_{6G} \times P_{7E} \times P_{27c} \times P_{2\bar{c}} \times P_{2\hat{c}} = 2.8808 \times 10^{-5}$	6G + 6E	2.2398×10^{-4}	1.7931×10^{-7}
			$24c + 2\bar{c} + 2\hat{c}$	6.0004×10^{-3}	
SUBTOTAL		2.8482×10^{-2}			1.7728×10^{-4}
CUMULATIVE TOTAL		.90913252			3.2543×10^{-4}

LEGEND

□ = G o = $\bar{c}$

Δ = E 0 = $\hat{c}$

▫ = C

$\lambda_E = 2.013\ (10^{-5})$

$$D_E = \frac{(MDT_{Tiline} \times \lambda_{Tiline}) + (MDT\ couplers \times \lambda couplers) + (MDT_{PS} \times \lambda_{PS})}{\lambda_E}$$

$= 1.9538$ hours

$$P_E = \frac{1}{1 + \lambda_E D_E}$$

$= .99996067$

The probability of seven part E's being available at any time is $P_{7E} = (P_E)^7 =$ .99972473. The probability of 6 part E's being available at anytime is $P_{6E} = 7(P_E)^6\ q_E$ where $q_E = 1 - P_E$. Thus, $P_{6E} = 2.7523\ (10^{-4})$.

3. Part C consists of the 28 computers contained within the seven ensembles; hence, like part E, the direct repair philosophy applies. For a single part C, $\lambda_C = 2.143\text{x}10^{-4}$ and $D_c = 2$. Then, using the same approach as for part E, $P_c = .99957158$, and $q_c = 4.2842\text{x}10^{-4}$. Although as few as 23 part C's need be available to maintain system operation, states containing less than 26 part C's will have insignificant state probabilities, hence will not be considered in this analysis. Then,

$P_{28C} = P_c^{28} = .98807336$

$P_{27C} = \binom{28}{1} P_c^{27} q_c = .01185777$

$P_{26C} = \binom{28}{2} P_c^{26} q_c^2 = 6.8611\text{x}10^{-5}$

4. Since part $\overline{c}$ is attached to the ATCRBS Tiline, which is critical to system operation, the 720-hour maintenance philosophy applies; therefore:

$P_{2\overline{c}} = e^{-U}$ where $U = 2 \times 2.143\ (10^{-4}) \times 720 = .308592$,

$P_{2\overline{c}} = .73448038$,

$P_{1\overline{c}} = Ue^{-U} = .22665477$, and

$P_{0\overline{c}} = 1 - P_{2c} - P_{1c} = .03886485$.

5. As part $\hat{c}$ is attached to the communications Tiline, which is critical to system operation, the 720-hour maintenance philosophy likewise applies; therefore:

$P_{3\hat{c}} = e^{-U}$ where $U = 3 \times 2.143\ (10^{-4}) \times 720 = .462888$,

$P_{3\hat{c}} = .62946313$, and

$P_{2\hat{c}} = Ue^{-U} = .29137093$.

Depending upon the particular operational state, system outage can occur upon failure of any 5, 6, or 7 part G's or E's; 23 or 24 part C's; 1 or 2 part $\bar{c}$'s; or 2 or 3 part $\hat{c}$'s. These failure rates are:

$$\lambda_{5G} = 5 \times \lambda_G = 5 \times 1.72\ (10^{-5}) = 8.6\ (10^{-5})$$

$$\lambda_{6G} = 6 \times \lambda_G = 6 \times 1.72\ (10^{-5}) = 1.034\ (10^{-4})$$

$$\lambda_{7G} = 7 \times \lambda_G = 7 \times 1.72\ (10^{-5}) = 1.204\ (10^{-4})$$

$$\lambda_{5E} = 5 \times \lambda_E = 5 \times 2.013\ (10^{-5}) = 1.0065\ (10^{-4})$$

$$\lambda_{6E} = 6 \times \lambda_E = 6 \times 2.013\ (10^{-5}) = 1.2078\ (10^{-4})$$

$$\lambda_{7E} = 7 \times \lambda_E = 7 \times 2.013\ (10^{-5}) = 1.4091\ (10^{-4})$$

$$\lambda_{23c} = 23 \times 2.143\ (10^{-4}) = 4.9289\ (10^{-3})$$

$$\lambda_{24c} = 24 \times 2.143\ (10^{-4}) = 5.1432\ (10^{-3})$$

$$\lambda_{1\bar{c}} = 2.143\ (10^{-4})$$

$$\lambda_{2\bar{c}} = \lambda_{2\hat{c}} = 4.286\ (10^{-4})$$

$$\lambda_{3\hat{c}} = 6.429\ (10^{-4})$$

Table A-1 shows the states and failure modes for all the significant states. Note that the configuration diagrams show the five parts of the composite by means of different symbols. A failure in any part is indicated by a solid symbol.

In state 33, all 30 ensemble computers (28C and $2\bar{c}$) and all three communications computers ($3\hat{c}$) are operational, therefore the probability of the composite being in state 33 is $P_{7G} \times P_{7E} \times P_{28C} \times P_{2\bar{c}} \times P_{3\hat{c}}$. Should a part C or $\bar{c}$ fail, 29 computers will still remain in the ensemble group; which is 3 more than the required 26. Should a communications computer ($\hat{c}$) fail, there will still be the required $2\hat{c}$, and the system will remain operational. Should either a G or an E part fail, the ensemble concerned, with its four computers, will be unavailable to the system, but there will still be 26 ensemble computers available. There are therefore no failure modes in state 33.

In state 32A, one of the computers in one of the seven ensembles (part C) has failed. In case of failure of a G or E part in any of the remaining 6 ensembles, there would now be only 25 computers left in the ensemble group. The ensemble group will then preempt the spare communications computer ($\hat{c}$) to provide the 26th computer. As there are now the required 26 computers in the ensemble group as well as the required two communications computers, there are therefore no failure modes in state 32A.

State 32B is similar to 32A with the exception that one of the two ensemble computers attached to the ATCRBS Tiline ($\bar{c}$) has failed. By similar reasoning, there are no failure modes in state 32B.

In state 32C, one of the three communications computers ($\hat{c}$) has failed. As there are now only two communications computers (surveillance and CIDIN) left, failure of either of these ($\lambda_{2\hat{c}}$) will cause system outage.

In state 31A, two computers in the same ensemble have failed. The expression for the state probability is obtained as follows. There are $\binom{4}{2}$ = 6 combinations of the failed computers within the ensemble containing them. There are $\binom{7}{1}$ = seven ways in which the ensemble containing the failed computers can be contained within the seven ensembles of the group. Hence, there are 7x6 = 42 combinations of state 31A. But there are a total of $\binom{28}{2}$ = 378 ways in which two failed C parts can occur among the 28 part C's in the ensemble group. This is equal to 1/9 P_{26C}. Failure of a G or E part in any of the other six ensembles would leave only 22 part C's left. Even with the two part $\bar{c}$'s and the redundant $\hat{c}$, there would still be only 25 computers available to the ensemble group, hence a system outage would occur.

In state 31B, the two failed computers occur in different ensembles. There are $\binom{4}{1}$ = 4 combinations of failed computers in each of the two ensembles, and there are $\binom{7}{2}$ = 21 combinations of these two ensembles among the seven ensembles of the group. Thus, there are 21 x 4 x 4 = 336 combinations of state 31B, which is equal to 8/9 P_{26C}. Should a G or E part in either of the two ensembles containing a failed computer fail, there would still be 23 part C's, 2 part $\bar{c}$'s, and the redundant $\hat{c}$ which would be preempted by the ensemble group to provide its required 26 computers. However, a failure in a G or E part of any of the other five ensembles would result in a total of only 25 computers in the ensemble group, thereby causing system outage.

The coefficients and failure modes for the remaining states are derived in a similar manner. In states 28A through 28G, one ensemble plus an additional $\bar{c}$, $\hat{c}$, or C part from another ensemble have failed. The redundant communications computer has been preempted by the ensemble group to provide the necessary 26 computers; hence, failure of <u>any</u> computer (C, $\bar{c}$, or $\hat{c}$), or failure of any of the remaining six ensembles will cause system outage.

The effective failure rate of the two-subsystem composite is:

$$\lambda_{EFF} = \frac{\Sigma(\text{State Probabilities x Failure Rates})}{\Sigma\text{State Probabilities}}$$

$$= \frac{3.2543\text{x}10^{-4}}{.90913252} = 357.96 \text{ failures per million hours}$$

The portion of this failure rate attributable to the $\binom{3}{2}$ communications computers (λ_{C1c}) is determined by those states where the redundant communications computer is in use by either of the two subsystems. These states are: 32C, 31D, 31E, 30B, 30C, 30E, 30F, 29B, 29C, and all seven versions of state 28.

Since the above states have no communications redundancy, failure of either of the two communications computers will cause system failure. Then,

$$\lambda_{C1c} = \frac{\lambda_{2\hat{c}} \left(P_{32C}+P_{31D}+P_{31E}+P_{30B}+P_{30C}+P_{30E}+P_{30F}+P_{29B}+P_{29C}+\sum_{i=A}^{G} P_{28i}\right)}{.90913252}$$

$$= 139.37 \text{ failures per million hours.}$$

The remainder of the effective failure rate is that of the $\binom{30}{26}$ ensemble computer group. This failure rate, $\lambda_{B2} = 357.96 - 139.37 = 218.59$ failures per million hours.

For the effective MDT calculations, the actual repair time (2-hour) philosophy will apply for all five parts. This will not change the part probabilities of the E and C ensemble parts, but for the G, $\bar{c}$, and $\hat{c}$ parts, the part probabilities are as follows:

$P_{7G} = .9997592331$

$P_{6G} = 2.407420233 \times 10^{-4}$

$P_{2\bar{c}} = .9991433508$

$P_{1\bar{c}} = 8.56465608 \times 10^{-4}$

$P_{0\bar{c}} = 1.8354205955 \times 10^{-7}$

$P_{3\hat{c}} = .9987153014$

$P_{2\hat{c}} = 1.284148135 \times 10^{-3}$

The 30 states of table A-1 are summarized in table A-2 using the above part probabilities for MDT determination. Since the numerator of the MDT expression is equal to the difference of two nearly equal quantities (i - Σ State Probabilities), some additional states must be considered in order to avoid large errors. These states are: 29F' and 28C', which are states 29F and 28C, with P_{6G} and P_{7E} interchanged with P_{7G} and P_{6E} in each. State 30G, representing all combinations of states where three part C's have failed, is also added.

The MDT for the composite turned out to be 1 hour, and will be used for both the ensemble group and the $\binom{3}{2}$ communications computers.

TABLE A-2. STATE SUMMARY FOR DETERMINATION OF MDT OF ENSEMBLE/COMMUNICATIONS COMPUTER COMPOSITE

State	Probability Expression	Numerical Value	Failure Mode Information: Failure Rate	Failure Mode Information: Prob. x Failure Rate
33	$P_{7G} \times P_{7E} \times P_{28c} \times P_{2\bar{c}} \times P_{3\hat{c}}$	.9854436038	-	-
32A	$P_{7G} \times P_{7E} \times P_{27c} \times P_{2\bar{c}} \times P_{3\hat{c}}$	.01182611161	-	-
32B	$P_{7G} \times P_{7E} \times P_{28c} \times P_{1\bar{c}} \times P_{3\hat{c}}$	$8.447222577 \times 10^{-4}$	-	-
32C	$P_{7G} \times P_{7E} \times P_{28c} \times P_{2\bar{c}} \times P_{2\hat{c}}$	$1.267083386 \times 10^{-3}$	4.286×10^{-4}	5.4307×10^{-7}
31A	$\frac{1}{9} \times P_{7G} \times P_{7E} \times P_{26c} \times P_{2\bar{c}} \times P_{3\hat{c}}$	$7.603007157 \times 10^{-6}$	2.2398×10^{-4}	1.7029×10^{-9}
31B	$\frac{8}{9} \times P_{7G} \times P_{7E} \times P_{26c} \times P_{2\bar{c}} \times P_{3\hat{c}}$	$6.082405725 \times 10^{-5}$	1.8665×10^{-4}	1.1353×10^{-8}
31C	$P_{7G} \times P_{7E} \times P_{27c} \times P_{1\bar{c}} \times P_{3\hat{c}}$	$1.013734288 \times 10^{-5}$	2.2398×10^{-4}	2.2706×10^{-9}
31D	$P_{7G} \times P_{7E} \times P_{27c} \times P_{2\bar{c}} \times P_{2\hat{c}}$	$1.520601431 \times 10^{-5}$	6.5258×10^{-4}	9.9231×10^{-9}
31E	$P_{7G} \times P_{7E} \times P_{28c} \times P_{1\bar{c}} \times P_{2\hat{c}}$	$1.086143879 \times 10^{-6}$	6.8991×10^{-4}	7.4934×10^{-10}
31F	$P_{7G} \times P_{7E} \times P_{28c} \times P_{0\bar{c}} \times P_{3\hat{c}}$	$1.810253652 \times 10^{-7}$	2.6131×10^{-4}	4.7304×10^{-11}
30A	$\frac{8}{9} \times P_{7G} \times P_{7E} \times P_{26c} \times P_{1\bar{c}} \times P_{3\hat{c}}$	$5.213838191 \times 10^{-8}$	2.6131×10^{-4}	1.3624×10^{-11}
30B	$\frac{1}{9} \times P_{7G} \times P_{7E} \times P_{26c} \times P_{2\bar{c}} \times P_{2\hat{c}}$	$9.775946606 \times 10^{-9}$	6.5258×10^{-4}	6.3796×10^{-12}
30C	$\frac{8}{9} \times P_{7G} \times P_{7E} \times P_{26c} \times P_{2\bar{c}} \times P_{2\hat{c}}$	$7.820757285 \times 10^{-8}$	6.8991×10^{-4}	5.3956×10^{-11}
30D	$P_{7G} \times P_{7E} \times P_{27c} \times P_{0\bar{c}} \times P_{3\hat{c}}$	$2.172449203 \times 10^{-9}$	2.6131×10^{-4}	5.6768×10^{-13}
30E	$P_{7G} \times P_{7E} \times P_{27c} \times P_{1\bar{c}} \times P_{2\hat{c}}$	$1.303459548 \times 10^{-8}$	6.8991×10^{-4}	8.9927×10^{-12}
	Subtotal	.999476714		5.692×10^{-7}
	Cumulative Total	.999476714		5.692×10^{-7}

TABLE A-2. STATE SUMMARY FOR DETERMINATION OF MDT OF ENSEMBLE/COMMUNICATIONS COMPUTER COMPOSITE (Continued)

State	Probability Expression	Numerical Value	Failure Mode Information: Failure Rate	Failure Mode Information: Prob. x Failure Rate
30F	$P_{7G} \times P_{7E} \times P_{28c} \times P_{0\bar{c}} \times P_{2\hat{c}}$	$2.327624146 \times 10^{-10}$	6.8991×10^{-4}	1.6059×10^{-13}
29A	$\frac{8}{9} \times P_{7G} \times P_{7E} \times P_{26c} \times P_{0\bar{c}} \times P_{3\hat{c}}$	$1.117334075 \times 10^{-11}$	2.6131×10^{-4}	2.9197×10^{-15}
29B	$8/9 \times P_{7G} \times P_{7E} \times P_{26c} \times P_{1\bar{c}} \times P_{2\hat{c}}$	$6.703953148 \times 10^{-11}$	6.8991×10^{-4}	4.6251×10^{-14}
29C	$P_{7G} \times P_{7E} \times P_{27c} \times P_{0\bar{c}} \times P_{2\hat{c}}$	$2.793335187 \times 10^{-12}$	6.8991×10^{-4}	1.9271×10^{-15}
29D	$P_{7G} \times P_{6E} \times P_{28c} \times P_{2\bar{c}} \times P_{3\hat{c}}$	$2.777177164 \times 10^{-4}$	2.2398×10^{-4}	6.22032×10^{-8}
29E	$P_{6G} \times P_{7E} \times P_{28c} \times P_{2\bar{c}} \times P_{3\hat{c}}$	$2.372948158 \times 10^{-4}$	2.2398×10^{-4}	5.31491×10^{-8}
29F	$\frac{1}{7} \times P_{6G} \times P_{7E} \times P_{27c} \times P_{2\bar{c}} \times P_{3\hat{c}}$	$4.068182393 \times 10^{-7}$	2.2398×10^{-4}	9.1119×10^{-11}
29G	$\frac{1}{7} \times P_{6G} \times P_{6E} \times P_{28c} \times P_{2\bar{c}} \times P_{3\hat{c}}$	$9.553489444 \times 10^{-9}$	2.2398×10^{-4}	2.13979×10^{-12}
28A	$P_{7G} \times P_{6E} \times P_{28c} \times P_{1\bar{c}} \times P_{3\hat{c}}$	$2.380596267 \times 10^{-7}$	6.22438×10^{-3}	1.48177×10^{-9}
28B	$P_{7G} \times P_{6E} \times P_{28c} \times P_{2\bar{c}} \times P_{2\hat{c}}$	$3.570894399 \times 10^{-7}$	6.22438×10^{-3}	2.22266×10^{-9}
28C	$\frac{6}{7} \times P_{6G} \times P_{7E} \times P_{27c} \times P_{2\bar{c}} \times P_{3\hat{c}}$	$2.440909436 \times 10^{-6}$	6.22438×10^{-3}	1.5193×10^{-8}
28D	$P_{6G} \times P_{7E} \times P_{28c} \times P_{1\bar{c}} \times P_{3\hat{c}}$	$2.034091197 \times 10^{-7}$	6.22438×10^{-3}	1.2661×10^{-9}
28E	$P_{6G} \times P_{7E} \times P_{28c} \times P_{2\bar{c}} \times P_{2\hat{c}}$	$3.051136794 \times 10^{-7}$	6.22438×10^{-3}	1.8991×10^{-9}
28F	$\frac{1}{7} \times P_{6G} \times P_{7E} \times P_{27c} \times P_{1\bar{c}} \times P_{3\hat{c}}$	$3.487245949 \times 10^{-10}$	6.22438×10^{-3}	2.17059×10^{-12}
28G	$\frac{1}{7} \times P_{6G} \times P_{7E} \times P_{27c} \times P_{2\bar{c}} \times P_{2\hat{c}}$	$5.230868922 \times 10^{-10}$	6.22438×10^{-3}	3.2559×10^{-12}
	Subtotal	$5.189746748 \times 10^{-4}$		1.3751×10^{-7}
	Cumulative Total	$9.999956887 \times 10^{-1}$		7.0671×10^{-7}

TABLE A-2. STATE SUMMARY FOR DETERMINATION OF MDT OF ENSEMBLE/COMMUNICATIONS COMPUTER COMPOSITE (Continued)

State	Probability Expression	Numerical Value	Failure Mode Information: Failure Rate	Failure Mode Information: Prob. x Failure Rate
29F′	$\frac{1}{7} \times P_{7G} \times P_{6E} \times P_{27c} \times P_{2\bar{c}} \times P_{3\hat{c}}$	$4.761192534 \times 10^{-7}$	2.2398×10^{-4}	1.0664×10^{-10}
28C′	$\frac{6}{7} \times P_{7G} \times P_{6E} \times P_{27c} \times P_{2\bar{c}} \times P_{3\hat{c}}$	$2.856715521 \times 10^{-6}$	6.22438×10^{-3}	1.7781×10^{-8}
30G	$P_{7G} \times P_{7E} \times P_{25c} \times P_{2\bar{c}} \times P_{3\hat{c}}$	$2.541746455 \times 10^{-7}$	Inconsequential	
	Subtotal	$3.58700942 \times 10^{-6}$		1.7888×10^{-8}
	Cumulative Total	$9.999992757 \times 10^{-1}$		7.24598×10^{-7}

$$MDT = \frac{1 - \Sigma \text{ State Probabilities}}{\Sigma(\text{State Probabilities} \times \text{Failure Rates})} = \frac{7.243(10^{-7})}{7.24598(10^{-7})} = 1.0 \text{ hour}$$

APPENDIX B

STATE DIAGRAM TECHNIQUE FOR DETERMINING THE EQUIVALENT FAILURE RATE OF THE $\binom{3}{2}$ SURVEILLANCE TRANSMIT COMBINATION

The probabilities of the various operational states of the surveillance transmit combination are functions of the probabilities of three element types. These are the serial elements of the communications I/F PCB's (S), the A and B channel elements of the communications I/F PCB's (A and B), and the modems associated with each channel element (MA and MB). Since a minimum of two of each element type is required to maintain the system operational, the probabilities involved are P_{3S}, P_{2S}, P_{3A}, P_{2A}, P_{3B}, P_{2B}, P_{3MA}, P_{2MA}, P_{3MB}, and P_{2MB}. Since the corresponding elements for channel A and B are identical, then $P_{3A} = P_{3B} = P_{3T}$; $P_{2MA} = P_{2MB} = P_{2M}$, etc.

Depending upon the particular operational state, system outage can occur upon failure of any of two or three part S's; or two part A's, B's, MA's, or MB's. Table B-1 shows the states and failure modes for all the significant operational states. S and T represent the serial and channel elements, respectively, of the communications I/F PCB's while M represents the modems.

In state 1, all elements are operational. Should one serial element fail, there will still be two channel A's and B's, and the system will remain operational. If an A or MA element fails, there will still be two A channels and three B channels, and the system will remain operational. There are, therefore, no failure modes in state 1.

In state 2, a PCB channel element for channel A has failed. Failure of either of the other two serial elements will leave only one A channel operational; hence, this causes a system outage. Likewise, failure of either of the remaining two A channel elements or their respective modems will leave only one remaining A channel with subsequent loss of system operation. Since there are three B channels available, failure of a B channel element or modem will not cause system loss. States 3, 4, and 5 are similar.

In state 6, both channel elements of a single communications I/F PCB have failed. Therefore, only two A and B channels are now available. Failure of a channel element or its associated modem in any of these remaining four channels will cause system outage.

In state 7, a channel A element in one PCB and a channel B element on a second PCB have failed. This leaves two A and two B channels. In addition to failure of any channel element or modem in these four channels, failure of any of the three serial elements will leave less than the required two A and B channels; hence, system loss will result.

The remaining failure modes are derived in a similar manner. The various configurations of each state are summarized in table 13 of the text.

TABLE B-1. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE DETERMINATION OF SURVEILLANCE TRANSMIT COMBINATION

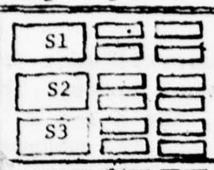
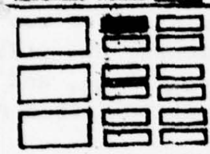
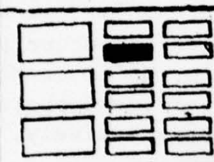
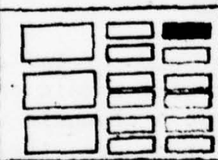
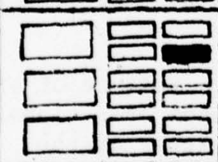
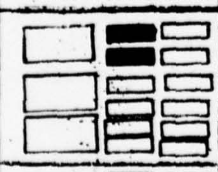
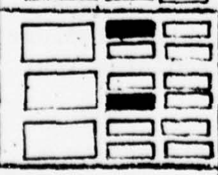
State	Configuration S T M	Probability	Failure Modes λ	Failure Rate	Prob.xFail. Rate
1 (A, B, A, B, A, B)		$P_1=P_{3S}\times P_{3A} \times P_{3B} \times P_{3MA} \times P_{3MB}$ =.95233508	-	-	-
2		$P_2=P_{3S}\times P_{2A} \times P_{3B}\times P_{3MA} \times P_{3MB}$	2S	2.224×10^{-5}	2.5436×10^{-7}
			2A	1.112×10^{-5}	1.2718×10^{-7}
		=.01143716	2MA	1.333×10^{-4}	1.5246×10^{-6}
3		$P_3=P_{3S}\times P_{3A} \times P_{2B}\times P_{3MA} \times P_{3MB}$	2S	2.224×10^{-5}	2.5436×10^{-7}
			2B	1.112×10^{-5}	1.2718×10^{-7}
		=.01143716	2MB	1.333×10^{-4}	1.5246×10^{-6}
4		$P_4=P_{3S}\times P_{3A} \times P_{3B}\times P_{2MA} \times P_{3MB}$	2S	2.224×10^{-5}	8.4719×10^{-9}
			2A	1.112×10^{-5}	4.2359×10^{-9}
		$=3.8093\times10^{-4}$	2MA	1.333×10^{-4}	5.0778×10^{-8}
5		$P_5=P_{3S}\times P_{3A} \times P_{3B}\times P_{3MA} \times P_{2MB}$	2S	2.224×10^{-5}	8.4719×10^{-9}
			2B	1.112×10^{-5}	4.2359×10^{-9}
		$=3.8093\times10^{-4}$	2MB	1.333×10^{-4}	5.0778×10^{-8}
6		$P_6=P_{3S}\times P_{2A/3} \times P_{2B/3}\times P_{3MA} \times P_{3MB}\times \binom{3}{2}$	2S	2.224×10^{-5}	1.0183×10^{-9}
			4T	2.224×10^{-5}	1.0183×10^{-9}
		$=4.5785\times10^{-5}$	4M	2.666×10^{-4}	1.2206×10^{-8}
7		$P_7=P_{3S}\times \frac{P_{2A}}{3} \times \binom{2}{1}\times \frac{P_{2B}}{3}\times P_{3MA} \times P_{3MB}\times \binom{3}{2}$	3S	3.336×10^{-5}	3.0548×10^{-9}
			4T	2.224×10^{-5}	2.0365×10^{-9}
		$=9.157\times10^{-5}$	4M	2.666×10^{-4}	2.4413×10^{-8}
SUBTOTAL		.97610862			3.983×10^{-6}
CUMULATIVE TOTAL		.97610862			3.983×10^{-6}

TABLE B-1. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE DETERMINATION OF SURVEILLANCE TRANSMIT COMBINATION (Continued)

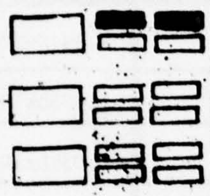
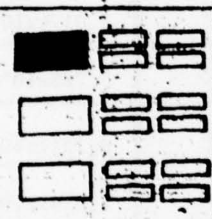
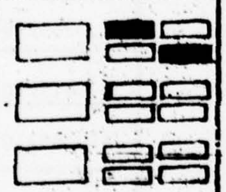
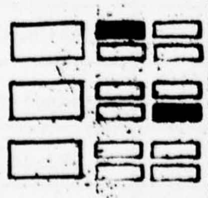
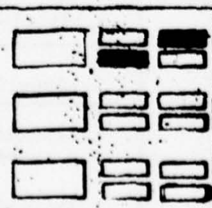
State	Configuration S T M	Probability	Failure Modes		
			λ	Failure Rate	Prob.xFail. Rate
8		$P_8=P_{3S}\times\frac{P_{2A}}{3}$	2S	2.224×10^{-5}	3.3916×10^{-11}
		$\times P_{3B}\times\frac{P_{2MA}}{3}$ $\times P_{3MB}\times(\frac{3}{2})$	2A	1.112×10^{-5}	1.6958×10^{-11}
		$=1.525\times10^{-6}$	2MA	1.333×10^{-4}	2.0328×10^{-10}
9		$P_9=P_{2S}\times$ $P_{3A}\times P_{3B}$	2S	2.224×10^{-5}	5.0872×10^{-7}
		$\times P_{3MA}\times P_{3MB}$ $=.02287433$	4T	2.224×10^{-5}	5.0872×10^{-7}
			4M	2.666×10^{-4}	6.0983×10^{-6}
10		$P_{10}=P_{3S}\times\frac{P_{2A}}{3}$	2S	2.224×10^{-5}	3.3916×10^{-11}
		$\times P_{3B}\times P_{3MA}$ $\times P_{2MB}/3\times(\frac{3}{2})$	4T	2.224×10^{-5}	3.3916×10^{-11}
		$=1.525\times10^{-6}$	4M	2.666×10^{-4}	4.0657×10^{-10}
11		$P_{11}=P_{3S}\times P_{2A}/3$ $\times P_{3B}\times P_{3MA}$	3S	3.336×10^{-5}	1.0174×10^{-10}
		$\times P_{2MB}/3\times(\frac{2}{1})$ $\times(\frac{3}{2})$	4T	2.224×10^{-5}	6.783×10^{-11}
		$=3.0499\times10^{-6}$	4M	2.666×10^{-4}	8.1311×10^{-10}
12		$P_{12}=P_{3S}\times P_{3A}$	2S	2.224×10^{-5}	3.3916×10^{-11}
		$\times\frac{P_{2B}}{3}\times\frac{P_{2MA}}{3}$ $\times P_{3MB}\times(\frac{3}{2})$	4T	2.224×10^{-5}	3.3916×10^{-11}
		$=1.525\times10^{-6}$	4M	2.666×10^{-4}	4.0657×10^{-10}
SUBTOTAL		.02288195			7.1179×10^{-6}
CUMULATIVE TOTAL		.99899057			11.101×10^{-6}

TABLE B-1. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE DETERMINATION OF SURVEILLANCE TRANSMIT COMBINATION (Continued)

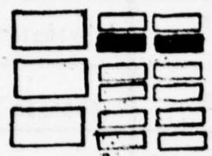
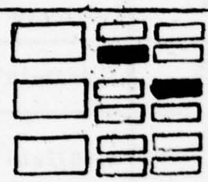
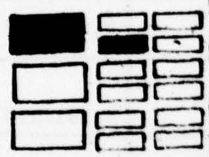
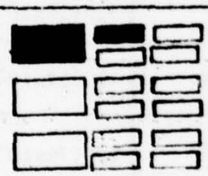
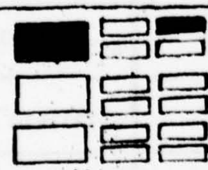
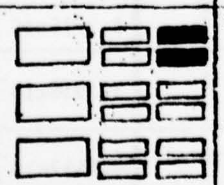
State	Configuration S T M	Probability	Failure Modes λ	Failure Rate	Prob.xFail.Rate
13		$P_{13}=P_{3S}xP_{3A}$ $x\frac{P_{2B}xP_{3MA}}{3}$	2S	$2.224x10^{-5}$	$3.3916x10^{-11}$
		$x\frac{P_{2MB}x(\frac{3}{2})}{3}$	2B	$1.112x10^{-5}$	$1.6958x10^{-11}$
		$=1.525x10^{-6}$	2MB	$1.333x10^{-4}$	$2.0328x10^{-10}$
14		$P_{14}=P_{3S}xP_{3A}$	3S	$3.336x10^{-5}$	$1.0174x10^{-10}$
		$x\frac{P_{2B}xP_{3MA}}{3}$	4T	$2.224x10^{-5}$	$6.783x10^{-11}$
		$x(\frac{2}{1})x\frac{P_{2MB}x(\frac{3}{2})}{3}$ $=3.0499x10^{-6}$	4M	$2.666x10^{-4}$	$8.1311x10^{-10}$
15		$P_{15}=\frac{P_{2S}}{3}xP_{3A}$	2S	$2.224x10^{-5}$	$2.0365x10^{-9}$
		$x\frac{P_{2B}xP_{3MA}}{3}$	4T	$2.224x10^{-5}$	$2.0365x10^{-9}$
		$xP_{3MB}x(\frac{3}{2})$ $=9.157x10^{-5}$	4M	$2.666x10^{-4}$	$2.4413x10^{-8}$
16		$P_{16}=\frac{P_{2S}}{3}x\frac{P_{2A}}{3}$	2S	$2.224x10^{-5}$	$2.0365x10^{-9}$
		$xP_{3B}xP_{3MA}$ $xP_{3MB}x(\frac{3}{2})$	4T	$2.224x10^{-5}$	$2.0365x10^{-9}$
		$=9.157x10^{-5}$	4M	$2.666x10^{-4}$	$2.4413x10^{-8}$
17		$P_{17}=\frac{P_{2S}}{3}xP_{3A}$	2S	$2.224x10^{-5}$	$6.783x10^{-11}$
		$xP_{3B}x\frac{P_{2MA}}{3}$	4T	$2.224x10^{-5}$	$6.783x10^{-11}$
		$xP_{3MB}x(\frac{3}{2})$ $=3.0499x10^{-6}$	4M	$2.666x10^{-4}$	$8.1311x10^{-10}$
18		$P_{18}=P_{3S}xP_{3A}$	2S	$2.224x10^{-5}$	$1.1296x10^{-12}$
		$xP_{3B}x\frac{P_{2MA}}{3}$	4T	$2.224x10^{-5}$	$1.1296x10^{-12}$
		$x\frac{P_{2MB}x(\frac{3}{2})}{3}$ $=5.0791x10^{-8}$	4M	$2.666x10^{-4}$	$1.3541x10^{-11}$
SUBTOTAL		$1.9082x10^{-4}$			$5.9178x10^{-8}$
CUMULATIVE TOTAL		.99918139			$11.16x10^{-6}$

TABLE B-1. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE DETERMINATION OF SURVEILLANCE TRANSMIT COMBINATION (Continued)

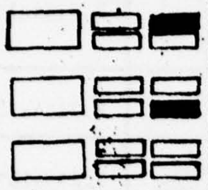
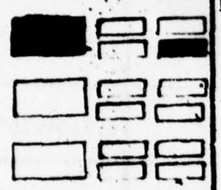
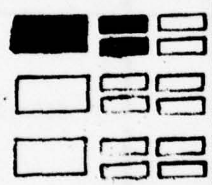
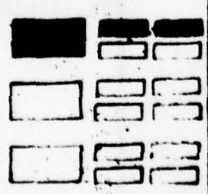
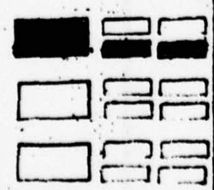
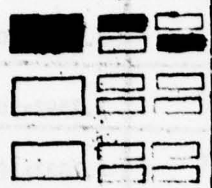
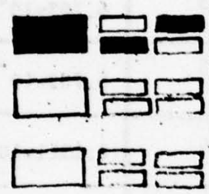
State	Configuration S T M	Probability	Failure Mode λ	Failure Rate	Prob.xFail.Rate
19		$P_{19}=P_{3S}\times P_{3A}\times P_{3B}\times \frac{P_{2MA}}{3}\times\binom{2}{1}\times\frac{P_{2MB}}{3}\times\binom{3}{2}$ $=1.0158\times10^{-7}$	3S	3.336×10^{-5}	3.3888×10^{-12}
			4T	2.224×10^{-5}	2.2592×10^{-12}
			4M	2.666×10^{-4}	2.7082×10^{-11}
20		$P_{20}=\frac{P_{2S}}{3}\times P_{3A}\times P_{3B}\times P_{3MA}\times\frac{P_{2MB}}{3}\times\binom{3}{2}$ $=3.0499\times10^{-6}$	2S	2.224×10^{-5}	6.783×10^{-11}
			4T	2.224×10^{-5}	6.783×10^{-11}
			4M	2.666×10^{-4}	8.1311×10^{-10}
21		$P_{21}=\frac{P_{2S}}{3}\frac{P_{2A}}{3}\times\frac{P_{2B}}{3}\times P_{3MA}\times P_{3MB}\times\binom{3}{2}$ $=3.7\times10^{-7}$	2S	2.224×10^{-5}	8.2288×10^{-12}
			4T	2.224×10^{-5}	8.2288×10^{-12}
			4M	2.666×10^{-4}	9.8642×10^{-11}
22		$P_{22}=\frac{P_{2S}}{3}\frac{P_{2A}}{3}\times P_{3B}\times\frac{P_{2MA}}{3}\times P_{3MB}\times\binom{3}{2}$ $=1.2209\times10^{-8}$	2S	2.224×10^{-5}	2.7154×10^{-13}
			4T	2.224×10^{-5}	2.7154×10^{-13}
			4M	2.666×10^{-4}	3.255×10^{-12}
23		$P_{23}=\frac{P_{2S}}{3}\times P_{3A}\times\frac{P_{2B}}{3}\times P_{3MA}\times\frac{P_{2MB}}{3}\times\binom{3}{2}$ $=1.2209\times10^{-8}$	2S	2.224×10^{-5}	2.7154×10^{-13}
			4T	2.224×10^{-5}	2.7154×10^{-13}
			4M	2.666×10^{-4}	3.255×10^{-12}
SUBTOTAL		3.5459×10^{-6}			1.1042×10^{-9}
CUMULATIVE TOTAL		0.99918494			1.161×10^{-6}

TABLE B-1. STATE DIAGRAM FOR EQUIVALENT FAILURE RATE DETERMINATION OF SURVEILLANCE TRANSMIT COMBINATION (Continued)

State	Configuration S T M	Probability	Failure λ	Failure Rate	Modes Prob.xFail. Rate
24		$P_{24} = \frac{P_{2S}}{3} \times \frac{P_{2A}}{3} \times P_{3B} \times P_{3MA} \times \frac{P_{2MB}}{3} \times (\frac{3}{2})$ $= 1.2209\times10^{-8}$	2S	2.224×10^{-5}	2.7154×10^{-13}
			4T	2.224×10^{-5}	2.7154×10^{-13}
			4M	2.666×10^{-4}	3.255×10^{-12}
25		$P_{25} = \frac{P_{2S}}{3} \times P_{3A} \times \frac{P_{2B}}{3} \times \frac{P_{2MA}}{3} \times P_{3MB} \times (\frac{3}{2})$ $= 1.2209\times10^{-8}$	2S	2.224×10^{-5}	2.7154×10^{-13}
			4T	2.224×10^{-5}	2.7154×10^{-13}
			4M	2.666×10^{-4}	3.255×10^{-12}
SUBTOTAL		2.4418×10^{-8}			7.5962×10^{-12}
CUMULATIVE TOTAL		.99918496			11.161×10^{-6}
λ Eff (Surveillance XMIT System) $= \frac{11.161\times10^{-6}}{.99918496}$				$= 11.17\times10^{-6}$	

State 1 of the summary corresponds to state 1 of table B-1.

State 2 of the summary corresponds to the sum of states 2 and 3 of table B-1.

State 3 of the summary corresponds to the sum of states 4 and 5 of table B-1.

State 4 of the summary corresponds to the sum of state 6 (with 2S + 4T + 4M failure rate) and state 7 (with 3S + 4T + 4M failure rate) of table B-1.

State 5 of the summary corresponds to the sum of states 8 and 13 (with 2S + 2T + 2M failure rates), states 10 and 12 (with 2S + 4T + 4M failure rates), and states 11 and 14 (with 3S + 4T + 4M failure rates) of table B-1.

State 6 of the summary corresponds to the sum of state 18 (with 2S + 4T + 4M failure rate) and state 19 (with 3S + 4T + 4M failure rates) of table B-1.

State 7 of the summary corresponds to state 9 of table B-1.

State 8 of the summary corresponds to the sum of states 15 and 16 of table B-1.

State 9 of the summary corresponds to the sum of states 17 and 20 of table B-1.

State 10 of the summary corresponds to state 21 of table B-1.

State 11 of the summary corresponds to the sum of states 22, 23, 24, and 25 of table B-1.

EQUIVALENT FAILURE RATE DETERMINATION

λ_S = Serial Element Failure Rate = 11.12×10^{-6}

$P_{3S} = e^{-u}$ where $u = 3 \times 11.12 \times 10^{-6} \times 720 = .0240192$

$P_{3S} = .97626697$ $\qquad P_{2S} = ue^{-u}$

$P_{2S} = .02344915$

$\lambda_A = \lambda_B$ = Channel A or B Transmit Element Failure Rate = 5.56×10^{-6}

$P_{3A} = P_{3B} = e^{-u}$ where $u = 3.5.56 \times 10^{-6} \times 720 = .0120096$

$P_{3A} = P_{3B} = e^{-.0120096}$; $P_{2A} = P_{2B} = Ue^{-u}$

$P_{3A} = P_{3B} = .98806223 = P_{3T}$

$P_{2A} = P_{2B} = .01186623 = P_{2T}$

λ_M = Failure Rate of Modem = 66.67×10^{-6}

U_M = Uptime of Modem = 15000 hours D_M = 2 hours

$$P_M = \frac{15000}{15002} = \frac{U_M}{U_M + D_M} \quad P3MA = P3MB = \left[\frac{15000}{15002}\right]^3$$

$$P_{3MA} = P_{3MB} = .99960011 = P_{3M}$$

$$P_{2MA} = P_{2MB} = 3\left[\frac{15000}{15002}\right]^2 \left[\frac{2}{15002}\right] = 3.9984 \times 10^{-4}$$

$$P_{2MA} = P_{2MB} = 3.9984 \times 10^{-4} = P_{2M}$$

$$\lambda_{2S} = 2.224 \times 10^{-5}$$

$$\lambda_{3S} = 3.336 \times 10^{-5}$$

$$\lambda_{2A} = \lambda_{2B} = 1.112 \times 10^{-5}$$

$$\lambda_{2A} + \lambda_{2B} = \lambda_{4T} = 2.224 \times 10^{-5}$$

$$\lambda_{2MA} = \lambda_{2MB} = 1.333 \times 10^{-4}$$

$$\lambda_{2MA} + \lambda_{2MB} = \lambda_{4M} = 2.66 \times 10^{-4}$$