

AFFDL-TR-78-18
Volume II

**MONTE CARLO BAYESIAN SYSTEM RELIABILITY —
AND MTBF-CONFIDENCE ASSESSMENT, II**
Volume II: SPARCS-2 Users Manual

MITCHELL O. LOCKS
OKLAHOMA STATE UNIVERSITY
STILLWATER, OKLAHOMA 74074

MARCH 1978

TECHNICAL REPORT AFFDL-TR-78-18, Volume II
Final Report March 1976 — December 1977

Approved for public release; distribution unlimited.

AIR FORCE FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

2006921108

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

H. Leon Harter

H. LEON HARTER
Project Engineer

Richard D. Krobussek

RICHARD D. KROBUSEK, Major, USAF
Chief, Analysis & Optimization Branch

FOR THE COMMANDER

Holland B. Lowndes, Jr.

HOLLAND B. LOWNDES, JR.
Acting Chief, Structural Mechanics Division

"If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify AFFDL/FBRD, W-PAFB, OH 45433 to help us maintain a current mailing list."

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFFDL-TR-78-18, Volume II	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SPARCS-2 Users Manual		5. TYPE OF REPORT & PERIOD COVERED Final Report March 1976-December 1977
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Mitchell O. Locks and Ross Gregson		8. CONTRACT OR GRANT NUMBER(s) F33615-76-C-3094
9. PERFORMING ORGANIZATION NAME AND ADDRESS Oklahoma State University College of Business Administration Stillwater, OK 74074		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 2304N104
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Flight Dynamics Laboratory/FBRD Air Force Wright Aeronautical Laboratories Air Force Systems Command Wright-Patterson Air Force Base, Ohio 45433		12. REPORT DATE March 1978
		13. NUMBER OF PAGES 44
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES AFFDL-TR-78-18, Volume I, is titled "Monte Carlo Bayesian Reliability- and MTBF-Confidence Assessment, II		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
Reliability	Poincaré's theorem	Conjugate prior
Monte Carlo	Complex systems	distribution
Assessment	Inclusion-exclusion	Modularization
System assessment	Bernoulli process	Poisson process
		Beta distribution
		Negative-log gamma
		distribution
		Minimal paths
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
This SPARCS-2 (Simulation Program for Assessing the Reliabilities of Complex Systems, Version 2) Users Manual provides the information and instructions for using the SPARCS-2 computer program. A glossary is included containing the general terminology and a description of the input terms. The manual also includes a general description of the program system capabilities and its operation as well as a listing of the specific functions performed by the program. In addition, sections containing usage instructions and control or operating		

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

Block 19 (Continued)

Minimal cuts	Subsystems	Pass-fail components
Probability	Failure modes	Time-to-failure components
Simulation	Component assessment	
Logic	MTBF assessments	

Block 20 (Continued)

instructions are also included. These instructions cover areas such as: data input format, formalized deck structure, and the procedure for putting SPARCS on a load module and for executing the stored program. Two example cases are also included which demonstrate setting up a problem, the input data deck, and the resulting output of the analysis.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

PREFACE

This users manual has been prepared as an aid to users of the SPARCS-2 computer program in assessing the reliability and/or the MTBF of complex systems, as discussed in Volume I of this report. Both volumes were prepared under Contract No. F33615-76-C-3094, which was technically monitored by Dr. H. Leon Harter. This work was performed under work unit 2304N104, System Reliability - Confidence Assessment.

TABLE OF CONTENTS

INTRODUCTION	1
COMPUTER PROGRAM SYSTEM CAPABILITIES	2
FUNCTION DESCRIPTION	4
USAGE INSTRUCTIONS	5
OPERATING INSTRUCTIONS	27
GLOSSARY	30
REFERENCES	32
APPENDIX	33

INTRODUCTION

This SPARCS-2 (Simulation Program for Assessing the Reliabilities of Complex Systems, Version 2) Users Manual provides the information and instructions for using the SPARCS-2 computer program. A glossary is included containing the general terminology and a description of the input terms. The manual also includes a general description of the program system capabilities and its operation as well as a listing of the specific functions performed by the program. In addition, sections containing usage instructions and control or operating instructions are also included. These instructions cover areas such as: data input format, formalized deck structure, and the procedure for putting SPARCS on a load module and for executing the stored program. Two example cases are also included which demonstrate setting up a problem, the input data deck, and the resulting output of the analysis.

SPARCS-2 is the result of a continuation of the research effort at Oklahoma State University for exact estimation and assessment of the reliabilities of complex systems, performed largely under the sponsorship of the Air Force Flight Dynamics Laboratory. The original version of SPARCS was programmed in 1975 by J. W. Cooley, and it is documented in both References [4] and [5]. Both SPARCS and SPARCS-2, being Monte Carlo programs, incorporate an estimation program MAPS (Method for the Analysis of the Probabilities of Systems) developed by J. L. Burris [1]. MAPS in turn is based on earlier FORTRAN programs developed at Rockwell International for NASA, documented in [2] and [3].

COMPUTER PROGRAM SYSTEM CAPABILITIES

Purpose

SPARCS-2 (Simulation Program for Assessing the Reliabilities of Complex Systems, Version 2) is a PL/I computer program for assessing (establishing interval estimates for) the reliability and the MTBF of a large and complex system of any modular configuration. The system can consist of a complex logical assembly of independently failing attribute (binomial-Bernoulli) and time-to-failure (Poisson-exponential) components, without regard to their placement. Alternatively, it can be a configuration of independently failing modules, where each module has either or both attribute and time-to-failure components.

SPARCS-2 also has an improved "super modularity" feature. Modules with minimal-cut unreliability calculations can be mixed with those having minimal-path reliability calculations. All output has been standardized to system reliability or "probability of success", regardless of the form in which the input data is presented, and whatever the configuration of modules or elements within modules.

General Description

The raw data for the reliability assessments are the component failure history data and the system configuration. The historical data are "successes and failures" for binomial-Bernoulli components and "failures and testing time (normalized to 'mission equivalent units')" for time-to-failure components. The configuration data consist of a list or lists of minimal

paths ("minimal path sets" or "tie sets"), or else a list of minimal cuts ("minimal cut sets"), for the system as a list of modules, and for each module as a list of components. If the MTBF assessment option is selected, the system "mission time" is also needed.

The underlying mathematical model is an amalgamation of Boolean logic, probability, and Bayesian and Monte Carlo techniques. The system reliability, a numerical-valued function of the component reliabilities, is derived by the method of inclusion-exclusion, also known as Poincaré's theorem, from the "minimal paths" or the "minimal cuts". The failure-history data are "sufficient statistics" for the parameters of Bayesian conjugate prior distributions (c.p.d.'s) on the component reliabilities, "beta" for attributes and "negative-log gamma" for time-to-failure.

Functions Performed

If the system minimal success states or "minimal paths" are input, a polynomial is generated which gives the system reliability as a function of the component reliabilities. By substituting component reliabilities into this function, the system reliability is obtained. Dually, if the system minimal failure states or "minimal cuts" are input, a polynomial is generated which gives the system unreliability as a function of the component unreliabilities.

SPARCS assesses by Monte Carlo. Through this process, the system reliability estimate for each Monte Carlo trial is obtained by substituting component probabilities into the function. At each trial, for each component, a value of the reliability is generated from the c.p.d. and

substituted into the system function, to obtain a value of the system reliability for that trial. The resulting "empirical" distribution of system reliabilities, obtained over a series of trials, provides the basis for an assessment. Percentage points on that distribution are interpreted as system reliability confidence limits. The corresponding MTBF confidence limits are calculated, based on the simple relationship between the reliability and the MTBF.

FUNCTION DESCRIPTION

There are 15 specific functions performed by the computer program and they are a part of the internal documentation included in the first four and one-half pages of computer output. The functions and procedure names included in the program are as follows:

ALGAMA	:	COMPUTES LOG OF GAMMA FUNCTION.
CABTA	:	GENERATES BETA DEVIATES.
COMPUTE	:	CALCULATES MODULE OR SYSTEM RELIABILITY OR UNRELIABILITY.
DATAGEN	:	COMPUTES COMPONENT PRIOR DISTRIBUTION MEAN RELIABILITIES.
EQGEN	:	GENERATES PROBABILITY EQUATIONS.
EQPUT	:	PRINTS OUT PROBABILITY EQUATIONS.
GAUSE.	:	GENERATES (0,1) NORMAL DEVIATES.
HDLIVE	:	PRINTS OUT SYSTEM IDENTIFICATION.
HISINF	:	PRINTS OUT FAILURE-HISTORY DATA FOR COMPONENTS AND PRIOR MEANS.
INPUT1,2,3,4	:	READS INPUT DATA.
MEANREL	:	COMPUTES MEAN COMPONENT RELIABILITIES FROM FAILURE-HISTORY DATA.
RANF	:	GENERATES UNIFORM PSEUDORANDOM DEVIATES.
RGAMA	:	GENERATES GAMMA DEVIATES.
SORT	:	PERFORMS 'SHELL' SORT.
STAT	:	COMPUTES AND PRINTS R AND MTBF AVERAGES, VARIANCES & PERCENTILES.

USAGE INSTRUCTIONS

Computer Input Terms

ATYPE	-	FLAG INDICATING RELIABILITY OR UNRELIABILITY COMPUTATION
MINPTH	-	BINARY VECTORS FOR MINIMAL PATH
NARG	-	SEED FOR RANDOM NUMBER GENERATION
NCOM	-	NUMBER OF COMPONENTS IN SYSTEM
NMOD	-	NUMBER OF MODULES IN SYSTEM
NPTH	-	NUMBER OF MINIMAL STATES IN SYSTEM
SIMNUM	-	NUMBER OF SIMULATIONS TO BE PERFORMED
SYSID	-	SYSTEM IDENTIFICATION
TIME	-	MISSION TIME
UNIT	-	TIME UNIT

Capacity

SPARCS-2 can process a system consisting of up to 128 modules or components in any configuration with up to 256 minimal states. Likewise, a module within the system can have 128 components and 256 minimal states. A probability equation can have up to 3500 terms.

Making Alterations to SPARCS-2 Program

Minor alterations can be made to SPARCS without great difficulty. For example, increasing the capacity for terms in the probability equation under a dynamic storage allocation can be done by augmenting the numerical argument for TERMS in the statement

DCL (MINPTH (128), TERMS (3500)) BIT (128) VAR.

If possible, alterations, when they are necessary, should be confined to

minor changes like increases in capacity or input-output modifications. Mathematical procedures such as EQGEN (probability equation generator), CABTA (beta random deviate generator), and RGAMA (gamma random deviate generator) can be changed only if there is sufficient background mathematical analysis. For example, the random deviate generators are checked out on 32-bit IBM-370 machines; extensive reprogramming would have to be done for other word sizes, or for the computer products of other manufacturers.

Substitution of Beta Components for Gamma Components

As this report went to press, it became apparent that certain field changes have to be made to the gamma generator incorporated into SPARCS-2. Until these changes are made, it will be necessary for users to substitute beta for gamma. This means treat all time-to-failure gamma components as if they were zero-one attribute beta components. This is easily done as explained below.

A gamma component has two historical data inputs: t , number of missions, and r , number of failures. A beta component also has two pieces of input data: s , successes, and r , failures. Both s and r are integers, whereas the gamma t is not necessarily an integer. All that is needed to make the substitution is an integer value of s which is a function of t and r . The following formula makes that conversion. Let

$$z = \left(\frac{t + 1}{t + 2} \right)^{r + 1}$$

denote the mean of the negative-log gamma conjugate prior distribution on the time-to-failure component reliability. Then

$$s \approx \frac{(b + 2)z - 1}{1 - z}; \quad (1)$$

that is, s is the integer closest to the right-hand side of (1). This conversion

was derived by equating the mean of the negative-log gamma distribution with the mean of the beta distribution.

Preparation of Inputs

The internal documentation of the program describes the preparation of the input data. The input data format is shown both for a system without modules and for a system with modules.

SYSTEM WITHOUT MODULES

DATA SET	NUMBER OF CARDS	COLUMN POSITION	DESCRIPTIONS
FIRST	1	1 - 80	ALPHANUMERIC SYSTEM IDENTIFICATION.
SECCND	1	1 - 4 6 - 14 16 - 20	NUMBER OF MONTE CARLO TRIALS. SEED VALUE FOR RANDOM NUMBER GENERATION (MUST BE A NON-ZERO POSITIVE INTEGER, $\leq 1.0 \text{ E}+09$). FOR EXAMPLE, 4527851 . SYSTEM MISSION TIME (OPTIONAL).
THIRD	1	1 - 3 5 - 7 9 - 13 14 15 - 19	(NUMERIC ZERO DENOTES NO MODULES). NUMBER OF COMPONENTS IN SYSTEM ($N \leq 129$) NUMBER OF SYSTEM MINIMAL STATES ($M \leq 257$). R FOR SYSTEM RELIABILITY, U FOR SYSTEM UNRELIABILITY. MISSION TIME UNITS, ALPHABETIC (OPTIONAL).
FOURTH	N	FREE FORMAT	ITEM1: '0'B FOR GAMMA (TIME-TO-FAILURE) OR '1'B FOR BETA (SUCCESS-FAILURE). ITEM2: NUMBER OF MISSIONS (GAMMA) OR SUCCESSES (BETA). ITEM3: NUMBER OF FAILURES.
FIFTH		FREE FORMAT	M MINIMAL STATES AS A STRING OF N-VECTORS SUCH AS '00110'B. COMPONENTS IN THE MINIMAL STATE ARE DENOTED BY 1, COMPONENTS NOT IN MINIMAL STATE BY 0.

EXAMPLE

```

COLUMN      000000000111111112222222223333333333
POSITION    123456789012345678901234567890123456789

CARD  6  '10'B  '01'B
      5  '1'B   95.  3.
      4  '0'B   99.  1.
      3      0    2    2PHOUR
      2    100 4527851 100
      1  TWO COMPONENT - TWO MINIMAL PATH SYSTEM

```

SYSTEM WITH MODULES

DATA SET	NUMBER OF CARDS	COLUMN POSITION	DESCRIPTION
FIRST	1	1 - 80	ALPHANUMERIC SYSTEM IDENTIFICATION.
SECCND	1	1 - 4 6 - 14 16 - 20	NUMBER OF MONTE CARLO TRIALS. SEED VALUE FOR RANDOM NUMBER GENERATION (MUST BE A NON-ZERO POSITIVE INTEGER, $\leq 1.0 \text{ E}+09$). FOR EXAMPLE, 2365142 . SYSTEM MISSION TIME (OPTIONAL).
THIRD	1	1 - 3 5 - 7 9 - 13 14 15 - 19	NUMBER OF MODULES IN SYSTEM (K<129). NUMBER OF COMPONENTS IN SYSTEM. NUMBER OF MINIMAL STATES IN SYSTEM (J<257). R FOR SYSTEM RELIABILITY, U FOR SYSTEM UNRELIABILITY. MISSION TIME UNITS, ALPHABETIC (OPTIONAL).
FOURTH		FREE FORMAT	J SYSTEM MINIMAL STATES AS A STRING OF BINARY K-VECTORS, SUCH AS '010'B. MODULES IN MINIMAL STATE ARE DENOTED BY 1, MODULES NOT IN MINIMAL STATE BY 0.
FIFTH		1 2 - 7 12 - 14 16 - 18	R FOR MODULE RELIABILITY, U FOR MODULE UNRELIABILITY. MODULE IDENTIFICATION, ALPHANUMERIC. NUMBER OF COMPONENTS IN MODULE (N<129) NUMBER OF MINIMAL STATES IN MODULE (M<257).
SIXTH	M	FREE FORMAT	ITEM1: '0'B FOR GAMMA (TIME-TO-FAILURE) OR '1'B FOR BETA (SUCCESS - FAILURE). ITEM2: NUMBER OF MISSIONS (GAMMA) OR SUCCESSES (BETA). ITEM3: NUMBER OF FAILURES.
SEVENTH		FREE FORMAT	M MODULE MINIMAL STATES AS A STRING OF BINARY N-VECTORS SUCH AS '01110'B. COMPONENTS IN MINIMAL STATE ARE DENOTED BY 1, COMPONENTS NOT IN MINIMAL STATE BY 0.

* THE FIFTH, SIXTH, AND SEVENTH DATA SETS ARE REPEATED FOR EACH MODULE.

EXAMPLE

```
COLUMN  00000000011111111222222222333333333
POSITION 123456789012345678901234567890123456789

CARD  12  '10'B  '01'B
      11  '1'B   90.  1.
      10  '0'B   92.  7.
           9  RB    2  2
           8  '01'B '10'B
           7  '0'B   95.  5.
           6  '1'B   99.  1.
           5  UA    2  2
           4  '0'B   '10'B
           3    2  2      2RCYCLE
           2    20 2365142  50
           1  TWO MODULES AND TWO COMPONENTS SYSTEM ANALYSIS
```

Results of Operation

Two cases of a sample problem will be used to demonstrate the rationale behind the problem design. The cards from the data deck are listed as well as the output format and a discussion of the output is included.

Sample Problem

The sample problem in this section is taken from a TRW internal publication [6] on software reliability. We show how it was run in different ways to illustrate some of the applications of the "super modularity" feature of SPARCS-2. The logical configuration can be either the system minimal paths (system reliability) or minimal cuts (system unreliability) with either the module minimal paths (module reliability) or minimal cuts (module unreliability). Since the output, a schedule of percentage points on an "empirical" distribution of the reliability, is

standardized to system reliability, the example also demonstrates the reproducibility of results.

The problem is illustrated by the flow diagram in Figure 1 and the corresponding network logic diagram in Figure 2, both of which are taken from [6]. It is identified in the reference as a "Triangle Type Determination Program (TTDP)" for structural-exercise test effectiveness measurement tools belonging to TRW's Product Assurance Confidence Evaluator (PACE) system.

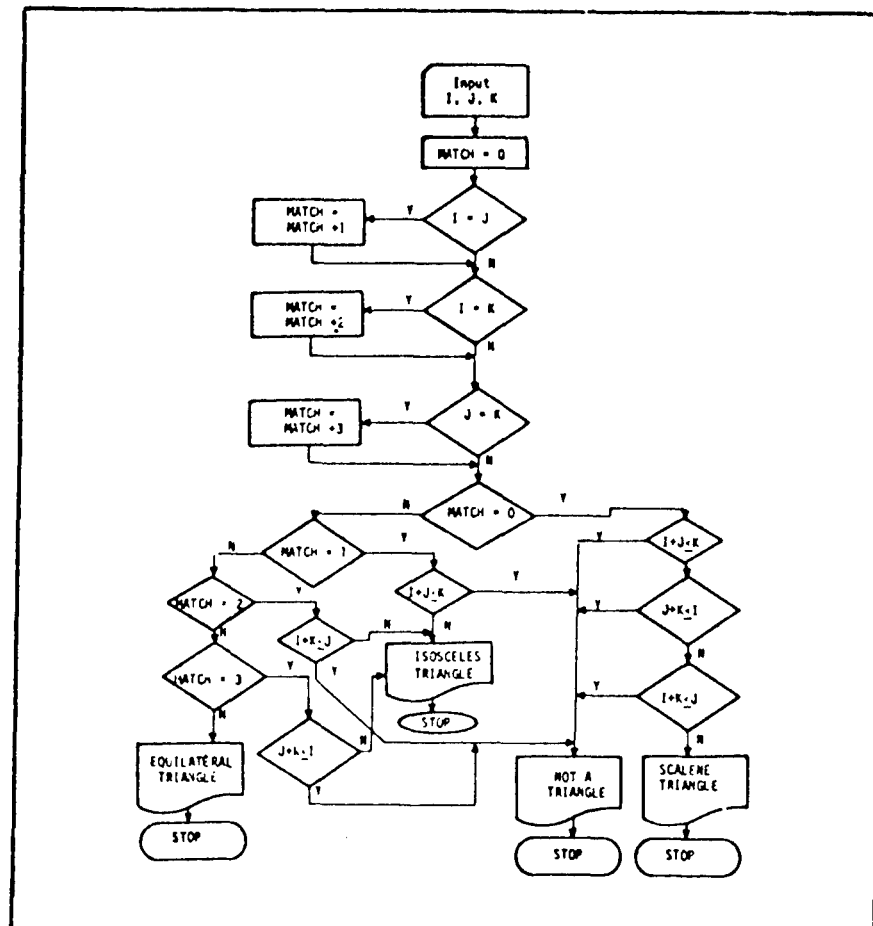


Figure 1. Flow Diagram of TTDP

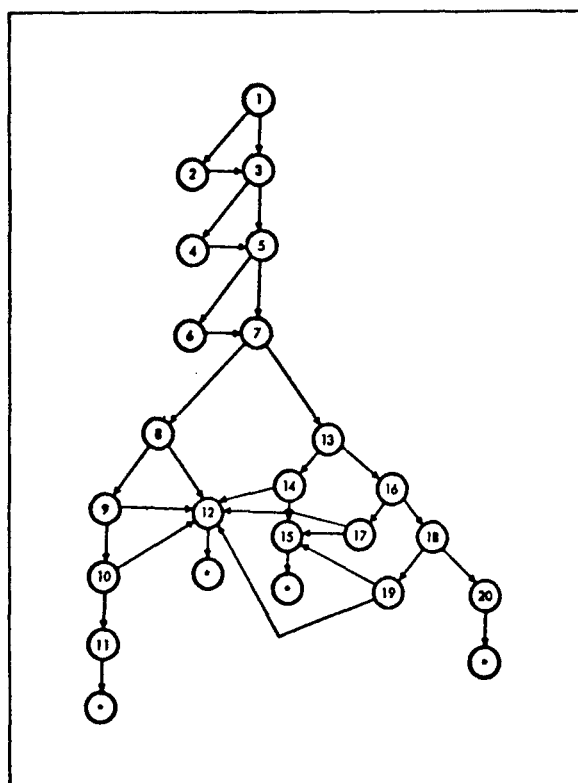


Figure 2. Network of Node-to-Node Branching Potential

The system was subdivided into two modules, A with components 1, ..., 7, and B with components 8, ..., 20. Since the SPARCS-2 program assigns sequence numbers to the components within each module by default, 8, ..., 20 were renumbered 1, ..., 13, respectively, so that there is a constant difference of 7 between the module-B component numbers in the computer output and in the description in the sequence. For example, 8 in the description is 1 in the computer output, 9 is 2, etc.

Module A represents the top half of Figure 2 and B the bottom half. Since both are needed, the system may be viewed either as two "successful" elements in series for reliability calculations, or else two failed elements

in parallel for unreliability calculations. Thus there is one minimal path

A, B

and there are two minimal cuts

A
B.

Since all four components 1, 3, 5, and 7 are needed for module A to be operative, it has one minimal path

1, 3, 5, 7

and four minimal cuts

1
3
5
7.

Components 2, 4, and 6 in module A are not essential, and do not affect the reliability calculations; module A will work even if all of them are inoperative, as long as 1, 3, 5, and 7 are all working properly.

Module B has nine minimal paths ("minimal path sets" or "tie sets")

13, 16, 18, 20
12, 13, 14
13, 14, 15
12, 13, 16, 17
13, 15, 16, 17
12, 13, 16, 18, 19
13, 15, 16, 18, 19
8, 9, 10, 11
8, 12

It is shown below that the module-B reliability equation based on these minimal paths is 91 terms long and requires a full page of computer output.

By inverting and minimalizing the minimal paths, we obtain the 26 minimal cuts ("minimal cut sets").

8, 13
8, 14, 16
9, 12, 13
10, 12, 13
11, 12, 13
8, 14, 17, 18
8, 12, 15, 16
8, 12, 15, 18
8, 12, 15, 20
9, 12, 15, 18
9, 12, 15, 20
9, 12, 14, 16
10, 12, 14, 16
10, 12, 15, 16
10, 12, 15, 18
10, 12, 15, 20
11, 12, 14, 16
11, 12, 15, 16
11, 12, 15, 18
11, 12, 15, 20
8, 14, 17, 19, 20
9, 12, 14, 17, 18
9, 12, 14, 17, 20
10, 12, 14, 17, 18
9, 12, 14, 17, 20
11, 12, 14, 17, 18

The module-B unreliability equation based on these 26 minimal cuts has 421 terms and requires four and one-half pages of computer output.

There are many different optional ways of inputting these data, based on either the paths (reliability) or the cuts (unreliability). The TRW-TTDP problem was run with eight different cases with the same historical input data for all components, and 20 Monte Carlo trials for each case.

1. System reliability - module A reliability - module B reliability.
2. System reliability - module A unreliability - module B reliability.
3. System reliability - module A unreliability - module B unreliability.
4. System unreliability - module A unreliability - module B reliability.
5. System reliability - module A unreliability - module B reliability.
6. System reliability - module A unreliability - module B unreliability.
7. System unreliability - module A reliability - module B reliability.
8. System unreliability - module A reliability - module B unreliability.

We discuss Cases 1 and 6 to illustrate the input and the output formats.

The results also show surprising consistency, demonstrating that an assessment with SPARCS-2 can be accomplished with relatively few Monte Carlo trials.

Case 1 is "all reliability", reliability for the system, and for module A and module B. The cards of the input data deck are listed below.

80/80

00000000111111112222222222333333
123456789012345678901234567890123456

```
CARD
0001      SOFTWARE RELIABILITY COMPUTATION
0002      20 15783      100
0003      2    2      1 RHOUR
0004      '11'B
0005      RA              7    1
0006          '0'B      96.5    2.
0007          '1'B      99.     1.
0008          '1'B      99.     1.
0009          '1'B      99.     1.
0010          '0'B      96.5    2.
0011          '1'B      99.     1.
0012          '1'B      99.     1.
0013      '1010101'B
0014      RB              13    9
0015          '0'B      96.5    2.
0016          '1'B      99.     1.
0017          '0'B      96.5    2.
0018          '1'B      99.     1.
0019          '0'B      96.5    2.
0020          '1'B      99.     1.
0021          '0'B      96.5    2.
0022          '1'B      99.     1.
0023          '0'B      96.5    2.
0024          '1'B      99.     1.
0025          '0'B      96.5    2.
0026          '1'B      99.     1.
0027          '0'B      96.5    2.
0028      '0000010010101'B
0029      '0000111000000'B
0030      '0000011100000'B
0031      '0000110011000'B
0032      '0000010111000'B
0033      '0000110010110'B
0034      '0000010110110'B
0035      '1111000000000'B
0036      '1000100000000'B
0037      $ENDLIST
```

The output is listed below. Following the system ID data, we have the minimal state or states, either paths or else cuts, the system probability function, either a reliability or an unreliability equation, the module-A minimal states, probability equation and component historical data, and the component-B minimal states, equation and historical data. Then follow various sets of statistical data relating to the output and finally the empirical distribution displaying the percentage points for assessment. The output format is practically the same as that in [5] for the original version of SPARCS.

* S P A R C S *
SIMULATION PROGRAM FOR THE ANALYSIS OF THE RELIABILITY OF COMPLEX SYSTEMS

SYSTEM IDENTIFICATION	SOFTWARE RELIABILITY COMPUTATION - J R BROWN AND LIPOW
NUMBER OF SIMULATIONS	20
NUMBER OF MODULES	2
NUMBER OF COMPONENTS	2
NUMBER OF MINIMAL PATHS	1
TYPE OF ANALYSIS	RELIABILITY

SPARCS :: EQUATION GENERATION ROUTINE

THE 1 MINIMAL PATH FOR SYSTEM

<A.8>

NUMBER OF TERMS IN EQUATION: 1

R = R R
SYS A B

THE 1 MINIMAL PATH FOR MODULE A

<1.3.5.7>

NUMBER OF TERMS IN EQUATION: 1

R = R R R R
A 1 3 5 7

HISTORICAL INFORMATION FOR EACH COMPONENT IN MODULE A

COMPONENT	TYPE	SUCCESS (BETA) EQUIVALENT MISSIONS(GAMMA)	FAILURES	PRIOR DISTRIBUTION MEAN
1	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.96985
2	ATTRIBUTE(BETA)	99.00	1.00	0.98039
3	ATTRIBUTE(BETA)	99.00	1.00	0.98039
4	ATTRIBUTE(BETA)	99.00	1.00	0.98039
5	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.96985
6	ATTRIBUTE(BETA)	99.00	1.00	0.98039
7	ATTRIBUTE(BETA)	99.00	1.00	0.98039

THE 9 MINIMAL PATHS FOR MODULE B

<6,9,11,13>
 <5,6,7>
 <6,7,8>
 <5,6,9,10>
 <6,8,9,10>
 <5,6,9,11,12>
 <6,8,9,11,12>
 <1,2,3,4>
 <1,5>

NUMBER OF TERMS IN EQUATION: 91

R = R R R R + R R R - R R R R R R + R R R - R R R R R R - R R R R + R R R R R R R + R R R R - R *
 B 6 9 11 13 5 6 7 5 6 7 9 11 13 6 7 8 6 7 8 9 11 13 5 6 7 8 5 6 7 8 9 11 13 5 6 9 10 5
 R R R R R - R R R R R + R R R R R R R + R R R R - R R R R R R R + R R R R R R - R R R R R R R R
 6 9 10 11 13 5 6 7 9 10 5 6 7 9 10 11 13 6 8 9 10 6 8 9 11 13 5 6 7 8 9 10 5 6 7 8 9 10 11 13
 - R R R R R + R R R R R R R - R R R R R + R R R R R R R + R R R R R - R R R R R R - R R R R R *
 6 7 8 9 10 6 7 8 9 10 11 13 5 6 8 9 10 5 6 8 9 10 11 13 5 6 9 11 12 5 6 9 11 12 13 5 6 7 9 11
 R + R R R R R R R - R R R R R R + R R R R R R R + R R R R R R R - R R R R R R R + R R R *
 12 5 6 7 9 11 12 13 5 6 9 10 11 12 5 6 9 10 11 12 13 5 6 7 9 10 11 12 5 6 7 9 10 11 12 13 6 8 9
 R R - R R R R R + R R R R R R - R R R R R R R - R R R R R + R R R R R R + R R R R R *
 11 12 6 8 9 11 12 13 5 6 7 8 9 11 12 5 6 7 8 9 11 12 13 6 7 8 9 11 12 6 7 8 9 11 12 13 5 6 8 9
 R R R - R R R R R R R - R R R R R R R + R R R R R R R R - R R R R R R + R R R R R R *
 10 11 12 5 6 8 9 10 11 12 13 5 6 7 8 9 10 11 12 5 6 7 8 9 10 11 12 13 6 8 9 10 11 12 6 8 9 10 11 12
 R + R R R R R R R - R R R R R R R R - R R R R R R + R R R R R R R + R R R R - R R R R R R R
 13 6 7 8 9 10 11 12 6 7 8 9 10 11 12 13 5 6 8 9 11 12 5 6 8 9 11 12 13 1 2 3 4 1 2 3 4 6 9 11 13
 - R R R R R R + R R R R R R R R + R R R R R R - R R R R R R R R - R R R R R R + R *
 1 2 3 4 6 7 8 1 2 3 4 6 7 8 9 11 13 1 2 3 4 5 6 7 8 1 2 3 4 5 6 7 8 9 11 13 1 2 3 4 6 8 9 10 1
 R R R R R R R - R R R R R R R R + R R R R R R R R R + R R R R R R R - R R R R R R *
 2 3 4 6 8 9 10 11 13 1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 10 11 13 1 2 3 4 6 7 8 9 10 1 2 3 4 6 7 8
 R R R R + R R R R R R R R - R R R R R R R R R R - R R R R R R R + R R R R R R R R - R *
 9 10 11 13 1 2 3 4 5 6 8 9 10 1 2 3 4 5 6 8 9 10 11 13 1 2 3 4 6 8 9 11 12 1 2 3 4 6 8 9 11 12 13 1
 R R R R R R R + R R R R R R R R R R + R R R R R R R R - R R R R R R R R - R R R *
 2 3 4 5 6 7 8 9 11 12 1 2 3 4 5 6 7 8 9 11 12 13 1 2 3 4 6 7 8 9 11 12 1 2 3 4 6 7 8 9 11 12 13 1 2 3
 R R R R R R R + R R R R R R R R R R + R R R R R R R R R - R R R R R R R R R R R
 4 5 6 8 9 10 11 12 1 2 3 4 5 6 8 9 10 11 12 13 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 13
 + R R R R R R R R R - R R R R R R R R R - R R R R R R R R + R R R R R R R R R R
 1 2 3 4 6 8 9 10 11 12 1 2 3 4 6 8 9 10 11 12 13 1 2 3 4 6 7 8 9 10 11 12 1 2 3 4 6 7 8 9 10 11 12 13
 + R R R R R R R R - R R R R R R R R R + R R - R R R R R - R R R + R R R R R R - R R *
 1 2 3 4 5 6 8 9 11 12 1 2 3 4 5 6 8 9 11 12 13 1 5 1 5 6 9 11 13 1 5 6 7 1 5 6 7 9 11 13 1 5
 R R R + R R R R R R + R R R R R - R R R R R R R - R R R R R + R R R R R R + R R R R *
 6 9 10 1 5 6 9 10 11 13 1 5 6 7 9 10 1 5 6 7 9 10 11 13 1 5 6 9 11 12 1 5 6 9 11 12 13 1 5 6 7
 R R - R R R R R R + R R R R R R R - R R R R R R R R - R R R R R R R + R R R R R R *
 9 11 12 1 5 6 7 9 11 12 13 1 5 6 9 10 11 12 1 5 6 9 10 11 12 13 1 5 6 7 9 10 11 12 1 5 6 7 9 10 11
 R R - R R R R + R R R R R R R
 12 13 1 2 3 4 5 1 2 3 4 5 6 9 11 13

HISTORICAL INFORMATION FOR EACH COMPONENT IN MODULE B

COMPONENT	TYPE	SUCCESS (BETA) EQUIVALENT MISSIONS(GAMMA)	FAILURES	PRIOR DISTRIBUTION MEAN
1	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.96985
2	ATTRIBUTE(BETA)	99.00	1.00	0.98039
3	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.96985
4	ATTRIBUTE(BETA)	99.00	1.00	0.98039
5	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.96985
6	ATTRIBUTE(BETA)	99.00	1.00	0.98039
7	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.96985
8	ATTRIBUTE(BETA)	99.00	1.00	0.98039
9	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.96985
10	ATTRIBUTE(BETA)	99.00	1.00	0.98039
11	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.96985
12	ATTRIBUTE(BETA)	99.00	1.00	0.98039
13	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.96985

SPARCS :: SYSTEM SIMULATION ROUTINE

SYSTEM RELIABILITY CALCULATED FROM MEAN COMPONENT RELIABILITIES IS 0.903486; SYSTEM UNRELIABILITY IS 0.096514

AVERAGE SYSTEM RELIABILITY FROM 20 MONTE CARLO TRIALS IS 0.901238 ; AVERAGE SYSTEM UNRELIABILITY IS 0.098762

VARIANCE 0.000671

STANDARD DEVIATION 0.025896

THE MISSION TIME IS 100.000 HOUR

THE ESTIMATED SYSTEM MTBF BASED UPON MEAN COMPONENT RELIABILITIES IS 9.85000000E+02

THE ESTIMATED SYSTEM MTBF BASED UPON MEAN SYSTEM RELIABILITY 20 MONTE CARLO TRIALS IS 9.61669678E+02

PERCENTILE	RELIABILITY PERCENTILE POINTS	MTBF PERCENTILE POINTS	
5.0 PERCENT	0.848968	6.10748047E+02	HOUR
10.0 PERCENT	0.865494	6.92260010E+02	HOUR
20.0 PERCENT	0.878241	7.70209473E+02	HOUR
25.0 PERCENT	0.884024	8.11221191E+02	HOUR
50.0 PERCENT	0.904296	9.94052002E+02	HOUR
75.0 PERCENT	0.921494	1.22310010E+03	HOUR
80.0 PERCENT	0.924841	1.27986133E+03	HOUR
90.0 PERCENT	0.925575	1.36934155E+03	HOUR
95.0 PERCENT	0.933471	1.45253003E+03	HOUR
97.5 PERCENT	0.937314	1.54470239E+03	HOUR
99.0 PERCENT	0.935619	1.60563623E+03	HOUR

Case 6 follows. Note that the module-B five-page probability equation with 421 terms based on 26 cuts is given with U's (for "unreliability") rather than R's (for "reliability"), as in the reliability equation for Case 1.

00000000111111111222222222333333333444444444555555555666666666777777
 12345678901234567890123456789012345678901234567890123456789012345

CARD

0001 SOFTWARE RELIABILITY - UNRELIABILITY COMPUTATION - J R BROWN AND LIPOW

0002 20 2794360 100

0003 2 2 1 RHOOR

0004 '11'B

0005 UA 7 4

0006 '0'B 96.5 2.

0007 '1'B 99. 1.

0008 '1'B 99. 1.

0009 '1'B 99. 1.

0010 '0'B 96.5 2.

0011 '1'B 99. 1.

0012 '1'B 99. 1.

0013 '1000000'B

0014 '0010000'B

0015 '0000100'B

0016 '0000001'B

0017 UB 13 26

0018 '0'B 96.5 2.

0019 '1'B 99. 1.

0020 '0'B 96.5 2.

0021 '1'B 99. 1.

0022 '0'B 96.5 2.

0023 '1'B 99. 1.

0024 '0'B 96.5 2.

0025 '1'B 99. 1.

0026 '0'B 96.5 2.

0027 '1'B 99. 1.

0028 '0'B 96.5 2.

0029 '1'B 99. 1.

0030 '0'B 96.5 2.

0031 '1000010000000'B

0032 '1000001010000'B

0033 '0100110000000'B

0034 '0010110000000'B

0035 '0001110000000'B

0036 '1000001001100'B

0037 '1000100110000'B

0038 '1000100100100'B

0039 '1000100100001'B

0040 '0100100100100'B

0041 '0100100100001'B

0042 '0100101010000'B

0043 '0010101010000'B

0044 '0010100110000'B

0045 '0010100100100'B

0046 '0010100100001'B

0047 '0001101010000'B

0048 '0001100110000'B

0049 '0001100100100'B

0050 '0001100100001'B

0051 '1000001001011'B

0052 '0100101001100'B

0053 '0100101001001'B

0054 '0010101001100'B

0055 '0100101001001'B

0056 '0001101001100'B

0057 \$ENDLIST

* S P A R C S *
SIMULATION PROGRAM FOR THE ANALYSIS OF THE RELIABILITY OF COMPLEX SYSTEMS

SYSTEM IDENTIFICATION	SOFTWARE RELIABILITY - UNRELIABILITY COMPUTATION - J R BROWN AND LIPOW
NUMBER OF SIMULATIONS	20
NUMBER OF MODULES	2
NUMBER OF COMPONENTS	2
NUMBER OF MINIMAL PATHS	1
TYPE OF ANALYSIS	RELIABILITY

SPARCS :: EQUATION GENERATION ROUTINE

THE 1 MINIMAL PATH FOR SYSTEM

<A,B>

NUMBER OF TERMS IN EQUATION: 1

R = R R
SYS A B

THE 4 MINIMAL CUTS FOR MODULE A

<1>
<3>
<5>
<7>

NUMBER OF TERMS IN EQUATION: 15

U = U + U - U U + U - U U - U U + U U U + U - U U - U U + U U U - U U + U U U + U U U - U U U U
A 1 3 1 3 5 1 5 3 5 1 3 5 7 1 7 3 7 1 3 7 5 7 1 5 7 3 5 7 1 3 5 7

HISTORICAL INFORMATION FOR EACH COMPONENT IN MODULE A

COMPONENT	TYPE	SUCCESS (BETA) EQUIVALENT MISSIONS(GAMMA)	FAILURES	PRIOR DISTRIBUTION MEAN
1	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.969851
2	ATTRIBUTE(BETA)	99.00	1.00	0.980392
3	ATTRIBUTE(BETA)	99.00	1.00	0.980392
4	ATTRIBUTE(BETA)	99.00	1.00	0.980392
5	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.969851
6	ATTRIBUTE(BETA)	99.00	1.00	0.980392
7	ATTRIBUTE(BETA)	99.00	1.00	0.980392

THE 26 MINIMAL CUTS FOR MODULE B

<1,6>
 <1,7,9>
 <2,5,6>
 <3,5,6>
 <4,5,6>
 <1,7,10,11>
 <1,5,8,9>
 <1,5,8,11>
 <1,5,8,13>
 <2,5,8,11>
 <2,5,8,13>
 <2,5,7,9>
 <3,5,7,9>
 <3,5,8,9>
 <3,5,8,11>
 <3,5,8,13>
 <4,5,7,9>
 <4,5,8,9>
 <4,5,8,11>
 <4,5,8,13>
 <1,7,10,12,13>
 <2,5,7,10,11>
 <2,5,7,10,13>
 <3,5,7,10,11>
 <2,5,7,10,13>
 <4,5,7,10,11>

NUMBER OF TERMS IN EQUATION: 421

$$\begin{aligned}
 U_8 = & U_{16} + U_{179} - U_{1679} + U_{256} - U_{1256} + U_{356} - U_{1356} - U_{2356} + U_{12356} + U_{456} - U_{1456} * \\
 & - U_{2456} + U_{12456} - U_{3456} + U_{13456} + U_{23456} - U_{123456} + U_{171011} - U_{1671011} - U_{179} * \\
 U_{1011} + & U_{16791011} + U_{1589} - U_{15689} - U_{15789} + U_{156789} + U_{15811} - U_{156811} - U_{157810} * \\
 U_{11} + & U_{156781011} + U_{157891011} - U_{1567891011} - U_{158911} + U_{1568911} + U_{15813} - U_{156} * \\
 U_{813} - & U_{158913} + U_{1568913} - U_{1581113} + U_{15681113} + U_{15891113} - U_{156891113} + U_{25811} * \\
 & + U_{1256811} - U_{256811} - U_{125811} + U_{25813} + U_{1256813} - U_{256813} + U_{12581113} - U_{1256} * \\
 U_{81113} - & U_{125813} - U_{2581113} + U_{25681113} + U_{2579} + U_{125679} - U_{12579} - U_{25679} + U_{12} * \\
 U_{578911} - & U_{125678911} + U_{12578913} - U_{125678913} - U_{1257891113} + U_{12567891113} * \\
 & - U_{2578911} + U_{25678911} - U_{2578913} + U_{25678913} + U_{257891113} - U_{2567891113} + U_3 * \\
 U_{579} + & U_{135679} - U_{13579} + U_{235679} - U_{1235679} - U_{35679} - U_{23579} + U_{123579} + U_{35} *
 \end{aligned}$$

$$\begin{aligned}
& 00 + 0000000 + 0000000 - 00000000 - 000000 - 000000 - 000000000 + 00000000 * \\
& 89 \quad 135689 \quad 135789 \quad 1356789 \quad 35689 \quad 13589 \quad 123578911 \quad 1235678 \\
& 00 - 00000000 + 0000000000 + 0000000000 - 00000000000 + 000000000 * \\
& 911 \quad 123578913 \quad 1235678913 \quad 12357891113 \quad 123567891113 \quad 23578911 \\
& - 000000000 + 00000000 - 000000000 - 000000000 + 0000000000 - 00000 * \\
& 235678911 \quad 23578913 \quad 235678913 \quad 2357891113 \quad 23567891113 \quad 3578 \\
& 0 + 0000000 + 00000 + 0000000 + 0000000 - 00000000 - 000000 + 0000000 - 0 * \\
& 9 \quad 356789 \quad 35811 \quad 1356811 \quad 2356811 \quad 12356811 \quad 356811 \quad 1358911 \quad 1 \\
& 0000000 - 000000 - 000000 + 0000000 - 000000 + 0000000 + 00000 + 0000000 \\
& 3568911 \quad 135811 \quad 235811 \quad 1235811 \quad 358911 \quad 3568911 \quad 35813 \quad 1356813 \\
& + 0000000 - 00000000 - 000000 + 0000000 - 00000000 + 0000000 - 0000000 * \\
& 2356813 \quad 12356813 \quad 356813 \quad 1358913 \quad 13568913 \quad 13581113 \quad 1356811 \\
& 0 - 00000000 + 000000000 - 000000 + 0000000 + 000000000 - 00000000 \\
& 13 \quad 135891113 \quad 1356891113 \quad 135813 \quad 23581113 \quad 1235681113 \quad 235681113 \\
& - 00000000 - 000000 + 0000000 - 000000 + 0000000 - 000000 + 0000000 + 0 * \\
& 123581113 \quad 235813 \quad 1235813 \quad 358913 \quad 3568913 \quad 3581113 \quad 35681113 \quad 3 \\
& 00000 - 0000000 + 00000 + 0000000 - 000000 + 0000000 - 00000000 + 00000 * \\
& 5891113 \quad 356891113 \quad 4579 \quad 145679 \quad 14579 \quad 245679 \quad 1245679 \quad 3456 \\
& 00 - 00000000 - 00000000 + 000000000 - 000000 - 000000 + 0000000 - 000000 + 0 * \\
& 79 \quad 1345679 \quad 2345679 \quad 12345679 \quad 45679 \quad 24579 \quad 124579 \quad 34579 \quad 1 \\
& 00000 + 0000000 - 00000000 + 00000 + 0000000 + 0000000 - 00000000 + 00000 * \\
& 34579 \quad 234579 \quad 1234579 \quad 4589 \quad 145689 \quad 145789 \quad 1456789 \quad 34568 \\
& 0 - 00000000 - 000000 - 000000 - 00000000 + 0000000000 - 000000000 + 00 * \\
& 9 \quad 1345689 \quad 45689 \quad 14589 \quad 124578911 \quad 1245678911 \quad 124578913 \quad 12 \\
& 0000000 + 000000000 - 00000000000 + 000000000 - 000000000 + 000000 * \\
& 45678913 \quad 12457891113 \quad 124567891113 \quad 24578911 \quad 245678911 \quad 24578 \\
& 00 - 000000000 - 0000000000 + 00000000000 + 0000000 + 000000000 - 00000 * \\
& 913 \quad 245678913 \quad 2457891113 \quad 24567891113 \quad 345789 \quad 13456789 \quad 1345 \\
& 000 - 00000000 - 000000 + 0000000 + 000000000 - 0000000000 + 0000000 * \\
& 789 \quad 3456789 \quad 34589 \quad 134589 \quad 1234578911 \quad 12345678911 \quad 1234578 \\
& 00 - 0000000000 - 00000000000 + 000000000000 - 0000000000 + 000000 * \\
& 913 \quad 12345678913 \quad 123457891113 \quad 1234567891113 \quad 234578911 \quad 23455 \\
& 0000 - 000000000 + 0000000000 + 00000000000 - 00000000000 - 000000 + 0 * \\
& 78911 \quad 234578913 \quad 2345678913 \quad 23457891113 \quad 234567891113 \quad 45789 \quad 4 \\
& 00000 + 00000 + 0000000 + 0000000 - 00000000 + 0000000 - 00000000 - 00 * \\
& 56789 \quad 45811 \quad 1456811 \quad 2456811 \quad 12456811 \quad 3456811 \quad 13456811 \quad 23 \\
& 00000 + 00000000 - 000000 + 0000000 - 00000000 - 000000 - 000000 + 00 * \\
& 456811 \quad 123456811 \quad 456811 \quad 1458911 \quad 4568911 \quad 145811 \quad 245811 \quad 12 \\
& 0000 + 0000000 + 000000000 - 00000000 - 00000000 - 000000 + 0000000 + 0 * \\
& 45811 \quad 3458911 \quad 134568911 \quad 34568911 \quad 13458911 \quad 345811 \quad 1345811 \quad 2
\end{aligned}$$

$$\begin{aligned}
& 000000 - 00000000 - 000000 + 0000000 + 00000 + 0000000 + 0000000 - 00000* \\
& 345811 \quad 12345811 \quad 458911 \quad 4568911 \quad 45813 \quad 1456813 \quad 2456813 \quad 1245* \\
& 000 + 0000000 - 00000000 - 00000000 + 000000000 - 000000 + 0000000 - 0* \\
& 6813 \quad 3456813 \quad 13456813 \quad 23456813 \quad 123456813 \quad 456813 \quad 1458913 \quad 1* \\
& 0000000 + 0000000 - 00000000 - 00000000 + 000000000 - 000000 + 000000* \\
& 4568913 \quad 14581113 \quad 145681113 \quad 145891113 \quad 1456891113 \quad 145813 \quad 2458* \\
& 00 + 000000000 - 00000000 - 00000000 - 00000000 - 00000 + 0000000 + 0000000 + 0* \\
& 1113 \quad 1245681113 \quad 245681113 \quad 124581113 \quad 245813 \quad 1245813 \quad 3458913 \quad 1* \\
& 00000000 - 00000000 - 00000000 + 0000000 + 000000000 + 000000000 - 0* \\
& 34568913 \quad 34568913 \quad 13458913 \quad 34581113 \quad 1345681113 \quad 2345681113 \quad 1* \\
& 000000000 - 00000000 + 000000000 - 000000000 - 00000000 - 000000* \\
& 2345681113 \quad 345681113 \quad 1345891113 \quad 13455891113 \quad 134581113 \quad 23458* \\
& 00 + 000000000 - 00000000 + 000000000 - 000000 + 0000000 + 0000000 \\
& 1113 \quad 1234581113 \quad 345891113 \quad 3456891113 \quad 345813 \quad 1345813 \quad 2345813 \\
& - 0000000 - 000000 + 0000000 - 000000 + 000000 + 0000000 - 000000* \\
& 12345813 \quad 458913 \quad 4568913 \quad 4581113 \quad 45681113 \quad 45891113 \quad 4568911* \\
& 0 + 0000000 - 00000000 - 00000000 + 00000000 - 00000000 + 000000000 \\
& 13 \quad 17101213 \quad 167101213 \quad 179101213 \quad 1679101213 \quad 1710111213 \quad 16710111213 \\
& + 00000000 - 000000000 + 000000000 - 000000000 + 000000000 \\
& 17910111213 \quad 167910111213 \quad 15789101213 \quad 156789101213 \quad 157810111213 \\
& - 000000000 - 000000000 + 00000000000 - 00000000 + 0000000* \\
& 1567810111213 \quad 1578910111213 \quad 15678910111213 \quad 1578101213 \quad 1567810* \\
& 00 + 000000 + 00000000 + 00000000 - 000000000 - 0000000 - 0000000* \\
& 1213 \quad 2571011 \quad 125671011 \quad 125791011 \quad 1255791011 \quad 25671011 \quad 12571011 \\
& - 00000000 + 000000000 + 00000000 - 00000000 - 0000000 + 000000* \\
& 1257891011 \quad 12567891011 \quad 125781011 \quad 1256781011 \quad 25781011 \quad 25678* \\
& 00 - 0000000 + 00000000 + 00000000 - 00000000 - 0000000 + 000000* \\
& 1011 \quad 25791011 \quad 256791011 \quad 257891011 \quad 2567891011 \quad 25671013 \quad 257810* \\
& 00 - 000000000 - 00000000 + 00000000 - 0000000 + 00000000 - 000000* \\
& 1113 \quad 25678101113 \quad 25781013 \quad 256781013 \quad 25791013 \quad 255791013 \quad 25789* \\
& 000 + 000000000 + 00000000 - 000000000 - 00000000 + 000000000 \\
& 101113 \quad 256789101113 \quad 257891013 \quad 2567891013 \quad 1257101213 \quad 12567101213 \\
& + 000000000 - 000000000 + 000000000 - 000000000 - 00000000 + 000000* \\
& 12579101213 \quad 125679101213 \quad 125710111213 \quad 1256710111213 \quad 125791011* \\
& 00 + 00000000000 - 0000000000 + 00000000000 - 0000000000 + 0* \\
& 1213 \quad 12567910111213 \quad 125789101213 \quad 1256789101213 \quad 1257810111213 \quad 1* \\
& 000000000 + 00000000000 - 00000000000 + 00000000000 - 000000* \\
& 2567810111213 \quad 12578910111213 \quad 125678910111213 \quad 12578101213 \quad 12567* \\
& 00000 - 0000000 + 00000000 + 00000000 - 000000000 + 000000 + 00* \\
& 8101213 \quad 257101113 \quad 2567101113 \quad 2579101113 \quad 25679101113 \quad 3571011 \quad 13*
\end{aligned}$$

U U U U U + U U U U U U - U U U U U U U + U U U U U U U - U U U U U U U - U U U U U U - U *
 5 6 7 10 11 1 3 5 7 9 10 11 1 3 5 6 7 9 10 11 2 3 5 6 7 10 11 1 2 3 5 6 7 10 11 3 5 6 7 10 11 1

U U U U U - U U U U U U U + U U U U U U U U + U U U U U U U - U U U U U U U + U U U U U U U *
 3 5 7 10 11 1 3 5 7 8 9 10 11 1 3 5 6 7 8 9 10 11 1 3 5 7 8 10 11 1 3 5 6 7 8 10 11 2 3 5 7 8 10 11

+ U U U U U U U U - U U U U U U U - U U U U U U U + U U U U U U U + U U U U U U U - U U *
 1 2 3 5 6 7 8 10 11 2 3 5 6 7 8 10 11 1 2 3 5 7 8 10 11 2 3 5 7 9 10 11 1 2 3 5 6 7 9 10 11 1 2

U U U U U U - U U U U U U U + U U U U U U U U - U U U U U U U U - U U U U U U U + U U U *
 3 5 7 9 10 11 2 3 5 6 7 9 10 11 1 2 3 5 7 8 9 10 11 1 2 3 5 5 7 8 9 10 11 2 3 5 7 8 9 10 11 2 3 5

U U U U U U - U U U U U U + U U U U U U U + U U U U U U U - U U U U U U U - U U U U U U + U U *
 6 7 8 9 10 11 3 5 7 9 10 11 3 5 6 7 9 10 11 3 5 7 8 9 10 11 3 5 6 7 8 9 10 11 3 5 7 8 10 11 3 5

U U U U U - U U U U U U + U U U U U U U + U U U U U + U U U U U + U U U U U U + U U U U U U *
 6 7 8 10 11 2 3 5 7 10 11 1 2 3 5 7 10 11 2 5 7 10 13 4 5 7 10 11 1 4 5 6 7 10 11 1 4 5 7 9 10

U - U U U U U U U + U U U U U U U - U U U U U U U + U U U U U U U - U U U U U U U - U U U *
 11 1 4 5 6 7 9 10 11 2 4 5 6 7 10 11 1 2 4 5 6 7 10 11 3 4 5 6 7 10 11 1 3 4 5 6 7 10 11 2 3 4

U U U U U + U U U U U U U - U U U U U U - U U U U U U - U U U U U U + U U U U U U U *
 5 6 7 10 11 1 2 3 4 5 6 7 10 11 4 5 6 7 10 11 1 4 5 7 10 11 1 4 5 7 8 9 10 11 1 4 5 6 7 8 9 10 11

+ U U U U U U - U U U U U U U + U U U U U U + U U U U U U U - U U U U U U U - U U U U *
 1 4 5 7 8 10 11 1 4 5 6 7 8 10 11 2 4 5 7 8 10 11 1 2 4 5 6 7 8 10 11 2 4 5 6 7 8 10 11 1 2 4 5

U U U U + U U U U U U + U U U U U U U U - U U U U U U U - U U U U U U U + U U U U U U U *
 7 8 10 11 2 4 5 7 9 10 11 1 2 4 5 6 7 9 10 11 1 2 4 5 7 9 10 11 2 4 5 6 7 9 10 11 1 2 4 5 7 8 9 10

U - U U U U U U U - U U U U U U U + U U U U U U U + U U U U U U U + U U U U U U U *
 11 1 2 4 5 6 7 8 9 10 11 2 4 5 7 8 9 10 11 2 4 5 6 7 8 9 10 11 3 4 5 7 9 10 11 1 3 4 5 6 7 9 10 11

- U U U U U U U + U U U U U U U - U U U U U U U - U U U U U U U - U U U U U U U + U *
 1 3 4 5 7 9 10 11 2 3 4 5 6 7 9 10 11 1 2 3 4 5 6 7 9 10 11 3 4 5 6 7 9 10 11 2 3 4 5 7 9 10 11 1

U U U U U U U - U U U U U U U - U U U U U U U U + U U U U U U U + U U U U U U U - U *
 2 3 4 5 7 9 10 11 3 4 5 7 8 9 10 11 1 3 4 5 6 7 8 9 10 11 1 3 4 5 7 8 9 10 11 3 4 5 6 7 8 9 10 11 1

U U U U U U U + U U U U U U U U U + U U U U U U U U - U U U U U U U U + U U U U U U U *
 2 3 4 5 7 8 9 10 11 1 2 3 4 5 6 7 8 9 10 11 2 3 4 5 7 8 9 10 11 2 3 4 5 6 7 8 9 10 11 3 4 5 7 8 10 11

+ U U U U U U U + U U U U U U U U - U U U U U U U U - U U U U U U U - U U U U U U U *
 1 3 4 5 6 7 8 10 11 2 3 4 5 6 7 8 10 11 1 2 3 4 5 6 7 8 10 11 3 4 5 6 7 8 10 11 1 3 4 5 7 8 10 11

- U U U U U U U + U U U U U U U U - U U U U U U + U U U U U U U + U U U U U U U - U U U U U *
 2 3 4 5 7 8 10 11 1 2 3 4 5 7 8 10 11 4 5 7 9 10 11 4 5 6 7 9 10 11 4 5 7 8 9 10 11 4 5 6 7 8 9

U U - U U U U U U + U U U U U U U - U U U U U U + U U U U U U U - U U U U U U + U U U U U U U *
 10 11 4 5 7 8 10 11 4 5 6 7 8 10 11 2 4 5 7 10 11 1 2 4 5 7 10 11 3 4 5 7 10 11 1 3 4 5 7 10 11

+ U U U U U U - U U U U U U U
 2 3 4 5 7 10 11 1 2 3 4 5 7 10 11

HISTORICAL INFORMATION FOR EACH COMPONENT IN MODULE B

COMPONENT	TYPE	SUCCESS (BETA)	FAILURES	PRIOR DISTRIBUTION
		EQUIVALENT MISSIONS(GAMMA)		MEAN
1	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.969851
2	ATTRIBUTE(BETA)	99.00	1.00	0.980392
3	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.969851
4	ATTRIBUTE(BETA)	99.00	1.00	0.980392
5	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.969851
6	ATTRIBUTE(BETA)	99.00	1.00	0.980392
7	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.969851
8	ATTRIBUTE(BETA)	99.00	1.00	0.980392
9	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.969851
10	ATTRIBUTE(BETA)	99.00	1.00	0.980392
11	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.969851
12	ATTRIBUTE(BETA)	99.00	1.00	0.980392
13	TIME-TO-FAILURE(GAMMA)	96.50	2.00	0.969851

SPARCS :: SYSTEM SIMULATION ROUTINE

SYSTEM RELIABILITY CALCULATED FROM MEAN COMPONENT RELIABILITIES IS 0.903486; SYSTEM UNRELIABILITY IS 0.096514

AVERAGE SYSTEM RELIABILITY FROM 20 MONTE CARLO TRIALS IS 0.909538 ; AVERAGE SYSTEM UNRELIABILITY IS 0.090462

VARIANCE 0.000625

STANDARD DEVIATION 0.024996

THE MISSION TIME IS 100.000 HOUR

THE ESTIMATED SYSTEM MTBF BASED UPON MEAN COMPONENT RELIABILITIES IS 9.85000000E+02

THE ESTIMATED SYSTEM MTBF BASED UPON MEAN SYSTEM RELIABILITY 20 MONTE CARLO TRIALS IS 1.05464673E+03

PERCENTILE	RELIABILITY PERCENTILE POINTS	MTBF PERCENTILE POINTS	
5.0 PERCENT	0.863285	6.80221680E+02	HOUR
10.0 PERCENT	0.874934	7.48464844E+02	HOUR
20.0 PERCENT	0.889750	8.56057129E+02	HOUR
25.0 PERCENT	0.893619	8.89078657E+02	HOUR
50.0 PERCENT	0.908336	1.04013916E+03	HOUR
75.0 PERCENT	0.927487	1.32843164E+03	HOUR
80.0 PERCENT	0.929598	1.36979785E+03	HOUR
90.0 PERCENT	0.943088	1.70660840E+03	HOUR
95.0 PERCENT	0.948863	1.90508569E+03	HOUR
97.5 PERCENT	0.951640	2.01741943E+03	HOUR
99.0 PERCENT	0.953307	2.09123511E+03	HOUR

It is both interesting and instructive to compare the results of the two outputs, as shown particularly in the assessment tables. The medians or 50-th percentiles are nearly identical, .904296 in Case 6 and .908336 in Case 1. For both problems, percentiles below the 80th are very close to each other. For specified percentiles above the 80th, Case 1 gave higher assessments. Since each output is based on only 20 Monte Carlo trials, these differences do not seem to be excessive. Even closer results would be and have been obtained with, say, 100 Monte Carlo trials.

OPERATING INSTRUCTIONS

The operating instructions for the SPARCS-2 program included in this manual are specific for the IBM series 370/158 (MVS environment) computer system in operation at the University Computer Center at Oklahoma State University. The system includes a PL/1 optimizing compiler. The control cards needed at any computer installation will depend upon local practices.

Instructions for Using Source Desk

The following desk structure may be used with the SPARCS-2 source desk. Note that the facsimilies for two of the 80-column control cards are shown split in half.

[illegible]

OSU. ACTXXXXX. SPARCS under the name SPARCS-2.

[illegible]

the disk library.

[illegible]

GLOSSARY

General Terminology

assessment: a schedule of system reliability or MTBF values as a function of the confidence coefficients, the component historical success-or-failure data and the system logical configuration, under an appropriate general statistical, probabilistic, and logical model.

Bayesian techniques: reliability assessment of components from prior distributions whose parameters are functions of available data.

Bernoulli process: governs the occurrence of failures for each pass-fail type component; the results of successive trials are independent and the probability of success on every trial is the component reliability.

beta component: success-or-failure attribute component.

beta distribution: for each pass-fail type component, the conjugate prior distribution on R is "beta", with its parameters being functions of prior failures and prior tests.

coherent system (coherence): the "zero" state $(0, \dots, 0)$, all components failed, is a system failure state or cut; the "one" state $(1, \dots, 1)$, all components succeeding, is a system success state or path; no paths are contained in any cuts, in the sense of partially ordered sets.

conjugate prior distribution: a prior distribution, such as beta or negative-log gamma, which has a similar mathematical form to the distribution describing events, and for which the parameters are sufficient statistics for the prior data.

gamma component: time-to-failure component.

MTBF: the average operating time between failures; defined only for systems with a mission time.

minimal cut: a set of components which, if they are all failed, cause the system to fail, but if any of them function (and all other components function), the system operates; the system is assumed to be coherent.

minimal path: a set of components which, if they are all functioning, permits the system to function, but if any of them fails (and no other components operate), the system fails; the system is assumed to be coherent.

modularization: by breaking the system up into a logical configuration of independently failing subsystems, as used herein, each system can be represented as a configuration of modules, with each module being a logical configuration of independently failing components.

Monte Carlo: beta or gamma random deviates are generated to obtain the component reliability (or unreliability) values which are substituted into the system probability function.

negative-log gamma distribution: for each time-to-failure component, the prior distribution on the component reliability is negative-log gamma, with its parameters being sufficient statistics for the prior data, failures, and testing time (normalized to mission-equivalent units).

Poincaré's theorem: builds the system reliability function recurrently one minimal path at a time from the minimal paths; dually, a system unreliability function can be built up from the minimal cuts; also known as the method of inclusion-exclusion.

Poisson process: assumed for each time-to-failure component; failures of individual components occur at a constant rate independent of prior history.

reliability: the probability that all assigned functions are performed within a predefined time frame and under the specified environment or environments: the probability of system success.

sufficient statistics: summary statistics which provide as much information about a random sample as if the value of every single observation were available.

super modularity: modules with minimal-cut unreliability calculations can be intermixed with those having minimal-path reliability calculations to obtain the system reliability, with no restrictions other than size and capacity limitations.

system: a configuration of modules unlike one another where each module is a configuration of possibly unlike components, with different failure-history data; beta and gamma components can be intermixed with no restriction on their placement.

REFERENCES

- [1] Burris, Jimmy L., "Model for the Analysis of the Probabilities of Systems," MBA research report, Department of Administrative Sciences, Oklahoma State University, 1972.
- [2] North American Rockwell Corporation Space Division, "Exact Minimal-Path Techniques for Determining System Reliability," Program MFS-16499; available through NASA's COSMIC, University of Georgia, Athens, GA 30601.
- [3] North American Rockwell Corporation Space Division, "System for Computing Operational Probability Equations (SCOPE): Version II," Program FMS-24035; available through NASA's COSMIC, University of Georgia, Athens, GA 30601.
- [4] Cooley, John W., "Simulation Program for Assessing the Reliability of Complex Systems (SPARCS)," Ph.D. dissertation, Oklahoma State University, April, 1976.
- [5] Locks, Mitchell O., "Monte Carlo Bayesian System Reliability- and MTBF-Confidence Assessment," Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, AFFDL-TR-75-144.
- [6] Brown, J. R. and M. Lipow, "Testing for Software Reliability," TRW Systems Engineering and Integration Division, One Space Park, Redondo Beach, CA 90278, TRW-SS-75-02, January, 1975.

APPENDIX. "SPARCS-2" SOURCE DECK LISTING

PL/I OPTIMIZING COMPILER

SPARCS2: PROC OPTIONS (MAIN):

PAGE 2

SOURCE LISTING

SYMT

```

1 SPARCS2: PROC OPTIONS (MAIN): 00000010
/* 00000020
/*-----00000030
/* 00000040
/* SPARCS2 (SIMULATION PROGRAM FOR ASSESSING THE RELIABILITIES OF 00000050
/* COMPLEX SYSTEM - VERSION 1) IS A SYSTEM OF PL/I PROCEDURES TO 00000060
/* ASSESS (PROVIDE INTERVAL ESTIMATES FOR) THE RELIABILITY & MTBF OF 00000070
/* A COMPLEX SYSTEM OF ANY LOGICAL CONFIGURATION. THE COMPONENTS CAN 00000080
/* BE EITHER ATTRIBUTE OR TIME-TO-FAILURE(TTF), WITH NO RESTRICTION 00000090
/* ON THEIR PLACEMENT. BAYESIAN AND MONTE CARLO TECHNIQUES ARE 00000100
/* EMPLOYED. INPUTS ARE MINIMAL STATES FOR SYSTEM AND ITS MODULES 00000110
/* AND COMPONENT FAILURE-HISTORY DATA. MINIMAL STATES ARE MINIMAL 00000120
/* PATHS FOR 'RELIABILITY' ANALYSIS OR MINIMAL CUTS FOR 00000130
/* 'UNRELIABILITY' ANALYSIS. OUTPUT IS A SCHEDULE OF SYSTEM 00000140
/* RELIABILITY AND MTBF VALUES AND ASSOCIATED CONFIDENCE LEVELS. 00000150
/* MTBF ANALYSIS IS OPTIONAL. FOR EACH COMPONENT, THE RAW DATA ARE 00000160
/* EXPERIENCED FAILURE HISTORIES: ACCUMULATED SUCCESSSES AND FAILURES 00000170
/* FOR ATTRIBUTES. EXPERIENCED TESTING TIME (NORMALIZED TO MISSION 00000180
/* EQUIPMENT UNITS) AND FAILURES FOR TTF COMPONENTS. THE SYSTEM 00000190
/* CAN CONSIST OF A COMPLEX CONFIGURATION OF UP TO 128 MODULES, EACH 00000200
/* MODULE BEING A COMPLEX CONFIGURATION OF UP TO 128 COMPONENTS. 00000210
/* MODULES WITH MINIMAL-PATH RELIABILITY ANALYSIS CAN OPTIONALLY BE 00000220
/* INTERMIXED WITH MODULES HAVING MINIMAL-CUT UNRELIABILITY 00000230
/* CALCULATIONS. THE SYSTEM CAN OPTIONALLY BE A CONFIGURATION OF 00000240
/* EITHER MINIMAL PATHS OR MINIMAL CUTS IN THE MODULES. OUTPUT IS 00000250
/* ALWAYS STANDARDIZED TO SYSTEM RELIABILITY AND ALSO MTBF IF REQUESTED. 00000260
/* DEFAULT LABELLING IS EMPLOYED FOR COMPONENTS AND MODULES IN 00000270
/* THE PROBABILITY EQUATION. COMPONENTS ARE NUMBERED SUCCESSIVELY 00000280
/* 1,2, ..., 128. MODULES ARE SEQUENCED ALPHANUMERICALLY A,B,C, ... 00000290
/* A1,B1: ...,A2,B2: ...,A22, A3,B3: ...,A23, A4,B4: ...,A24, 00000300
/* REFERENCES: 00000310
/* M.D. LOCKS, MONTE CARLO BAYESIAN SYSTEM RELIABILITY & 00000320
/* MTBF CONFIDENCE ASSESSMENT, TECHNICAL 00000330
/* REPORT AFFDL-TR-75-144, AIR FORCE FLIGHT 00000340
/* DYNAMICS LABORATORY, AIR FORCE SYSTEMS 00000350
/* COMMAND, WRIGHT PATTERSON AIR FORCE BASE, 00000360
/* 1975. 00000370
/* M.D. LOCKS, RELIABILITY, MAINTAINABILITY, & AVAILABILITY 00000380
/* ASSESSMENT, MAYDEN BOOK CO., 1972. 00000390
/* K.R. LEE, REJECTION METHODS FOR GENERATING RANDOM 00000400
/* DEVIATES & THEIR APPLICATIONS IN SYSTEM 00000410
/* RELIABILITY, MASTER'S THESIS, COMPUTING & 00000420
/* INFORMATION SCIENCES, J.S.U., 1972. 00000430
/* J.W. COOLEY, SIMULATION PROGRAM FOR ASSESSING THE 00000440
/* RELIABILITY OF COMPLEX SYSTEMS (SPARCS), 00000450

```

PL/I OPTIMIZING COMPILER

SPARCS2: PROC OPTIONS (MAIN):

PAGE 3

SYMT

```

/* PH.D. THESIS, OKLAHOMA STATE UNIVERSITY, 00000470
/* 1976. 00000480
/* J.P. CHANDLER, RAND-UNIFORMLY DISTRIBUTED PSEUDO- 00000490
/* RANDOM NUMBERS, UNPUBLISHED DOCUMENT, 00000500
/* DEPT OF COMPUTING & INFORMATION SCIENCES 00000510
/* O OKLAHOMA STATE UNIVERSITY, 1970. 00000520
/* J.L. BURRIS, MODEL FOR THE ANALYSIS OF PROBABILITIES 00000530
/* OF SYSTEMS (MAPS), MSA RESEARCH REPORT, 00000540
/* OKLAHOMA STATE UNIVERSITY, 1972. 00000550
/* 00000560
/* PROCEDURE NAMES USED: 00000570
/* 00000580
/* 00000590
/* ALGAMA 1 COMPUTES LOG OF GAMMA FUNCTION. 00000600
/* CABTA 1 GENERATES BETA DEVIATES. 00000610
/* COMPUTE 1 CALCULATES MODULE OR SYSTEM 00000620
/* RELIABILITY OR UNRELIABILITY. 00000630
/* DATAGEN 1 COMPUTES COMPONENT PRIOR 00000640
/* DISTRIBUTION MEAN RELIABILITIES. 00000650
/* EDEGEN 1 GENERATES PROBABILITY EQUATIONS. 00000660
/* EQUIT 1 PRINTS OUT PROBABILITY EQUATIONS. 00000670
/* GAUSF 1 GENERATES (0,1) NORMAL DEVIATES. 00000680
/* HLINE 1 PRINTS OUT SYSTEM IDENTIFICATION. 00000690
/* MISINF 1 PRINTS OUT FAILURE-HISTORY DATA FOR 00000700
/* COMPONENTS AND PRIOR MEANS. 00000710
/* INPUT1,2,3,4 1 READS INPUT DATA. 00000720
/* MEANREL 1 COMPUTES MEAN COMPONENT RELIABILITIES 00000730
/* FROM FAILURE-HISTORY DATA. 00000740
/* RAND 1 GENERATES UNIFORM PSEUDORANDOM 00000750
/* DEVIATES. 00000760
/* RGAMA 1 GENERATES GAMMA DEVIATES. 00000770
/* SORT 1 PERFORMS 'SHELL' SORT. 00000780
/* STAT 1 COMPUTES AND PRINTS R AND MTBF 00000790
/* AVERAGES, VARIANCES & PERCENTILES. 00000800
/* 00000810
/* 00000820
/* INPUT VARIABLES: 00000830
/* ATYPE - FLAG INDICATING RELIABILITY OR 00000840
/* UNRELIABILITY COMPUTATION 00000850
/* MINPTH - BINARY VECTORS FOR MINIMAL PATH 00000860
/* NARG - SEED FOR RANDOM NUMBER GENERATION 00000870
/* NCOM - NUMBER OF COMPONENTS IN SYSTEM 00000880
/* NMOD - NUMBER OF MODULES IN SYSTEM 00000890
/* NPAT - NUMBER OF MINIMAL STATES IN SYSTEM 00000900
/* SIMNUM - NUMBER OF SIMULATIONS TO BE PERFORMED 00000910
/* SYSID - SYSTEM IDENTIFICATION 00000920
/* TIME - MISSION TIME 00000930
/* UNIT - TIME UNIT 00000940
/* 00000950

```

STMT

```

/* INPUT DATA FORMAT:
/*
/* ** SYSTEM WITHOUT MODULES **
/*
/* DATA NUMBER COLUMN DESCRIPTIONS
/* SET OF CARDS POSITION
/*
/* FIRST 1 1 - 80 ALPHANUMERIC SYSTEM IDENTIFICATION.
/*
/* SECOND 1 1 - 4 NUMBER OF MONTE CARLO TRIALS.
/* 4 - 14 SEED VALUE FOR RANDOM NUMBER.
/* GENERATION (MUST BE A NON-ZERO
/* POSITIVE INTEGER, <= 1.0 E+09). FOR
/* EXAMPLE, 4527851.
/* SYSTEM MISSION TIME (OPTIONAL).
/*
/* THIRD 1 1 - 3 INUMERIC ZERO DENOTES NO MODULES.
/* 5 - 7 NUMBER OF COMPONENTS IN SYSTEM(K<129).
/* 9 - 13 NUMBER OF SYSTEM MINIMAL STATES
/* (M<257).
/* R FOR SYSTEM RELIABILITY, U FOR
/* SYSTEM UNRELIABILITY.
/* 15 - 19 MISSION TIME UNITS, ALPHABETIC
/* (OPTIONAL).
/*
/* FOURTH N FREE FORMAT ITEM1: '0'B FOR GAMMA (TIME-TO-
/* FAILURE) OR '1'B FOR BETA
/* (SUCCESS-FAILURE).
/* ITEM2: NUMBER OF MISSIONS (GAMMA) OR
/* SUCCESSES (BETA).
/* ITEM3: NUMBER OF FAILURES.
/*
/* FIFTH FREE FORMAT R MINIMAL STATES AS A STRING OF
/* N-VECTORS, SUCH AS '00110'B.
/* COMPONENTS IN THE MINIMAL STATE ARE
/* DENOTED BY 1. COMPONENTS NOT IN
/* MINIMAL STATE BY 0.
/*
/* EXAMPLE
/*
/* COLUMN 00000000111111112222222233333333
/* POSITION 123456789012345678901234567890123456789
/*
/* CARD 4 '10'B '01'B
/* 5 '1'B 99. 3.
/* 4 '0'B 99. 1.

```

STMT

```

/* 3 0 2 24HOUR
/* 2 100 4527851 100
/* 1 TWO COMPONENT - TWO MINIMAL PATH SYSTEM
/*
/* ** SYSTEM WITH MODULES **
/*
/* DATA NUMBER COLUMN DESCRIPTION
/* SET OF CARDS POSITION
/*
/* FIRST 1 1 - 80 ALPHANUMERIC SYSTEM IDENTIFICATION.
/*
/* SECOND 1 1 - 4 NUMBER OF MONTE CARLO TRIALS.
/* 4 - 14 SEED VALUE FOR RANDOM NUMBER.
/* GENERATION (MUST BE A NON-ZERO
/* POSITIVE INTEGER, <= 1.0 E+09). FOR
/* EXAMPLE, 12345142.
/* SYSTEM MISSION TIME (OPTIONAL).
/*
/* THIRD 1 1 - 3 NUMBER OF MODULES IN SYSTEM (K<129).
/* 5 - 7 NUMBER OF COMPONENTS IN SYSTEM.
/* 9 - 13 NUMBER OF MINIMAL STATES IN SYSTEM
/* (J<257).
/* R FOR SYSTEM RELIABILITY, U FOR
/* SYSTEM UNRELIABILITY.
/* 15 - 19 MISSION TIME UNITS, ALPHABETIC
/* (OPTIONAL).
/*
/* FOURTH FREE FORMAT J SYSTEM MINIMAL STATES AS A STRING
/* OF BINARY K-VECTORS, SUCH AS '010'B.
/* MODULES IN MINIMAL STATE ARE DENOTED
/* BY 1; MODULES NOT IN MINIMAL STATE
/* BY 0.
/*
/* FIFTH 1 R FOR MODULE RELIABILITY, U FOR
/* MODULE UNRELIABILITY.
/* 2 - 7 MODULE IDENTIFICATION, ALPHANUMERIC.
/* 12 - 14 NUMBER OF COMPONENTS IN MODULE (K<129).
/* 16 - 18 NUMBER OF MINIMAL STATES IN MODULE
/* (M<257).
/*
/* SIXTH N FREE FORMAT ITEM1: '0'B FOR GAMMA (TIME-TO-
/* FAILURE) OR '1'B FOR BETA
/* (SUCCESS - FAILURE).
/* ITEM2: NUMBER OF MISSIONS (GAMMA) OR
/* SUCCESSES (BETA).

```

SYMT

```

/*
/*          ITEMS: NUMBER OF FAILURES.          */00001940
/*          FREE FORMAT  N MODULE MINIMAL STATES AS A STRING */00001950
/*          OF BINARY N-VECTORS SUCH AS          */00001960
/*          '01101010'. COMPONENTS IN MINIMAL STATE */00001970
/*          ARE DENOTED BY 1. COMPONENTS NOT IN     */00001980
/*          MINIMAL STATE BY 0.                   */00001990
/*          * THE FIFTH, SIXTH, AND SEVENTH DATA SETS ARE REPEATED FOR EACH */00002000
/*          MODULE.                                     */00002010
/*
/*          EXAMPLE                                     */00002020
/*
/*          COLUMN 000000000111111111222222222333333333 */00002030
/*          POSITION 123456789012345678901234567890123456789 */00002040
/*
/*          CARD 12  *10'B  *01'B          */00002050
/*          11  *1'B  90.  1.          */00002060
/*          10  *0'B  92.  7.          */00002070
/*          9   RB  2  2          */00002080
/*          8   *01'B  *10'B          */00002090
/*          7   *0'B  95.  5.          */00002100
/*          6   *1'B  99.  1.          */00002110
/*          5   UA  2  2          */00002120
/*          4   *0'B  *10'B          */00002130
/*          3   2  2  2RCYCLE          */00002140
/*          2   20 2365142 50          */00002150
/*          1   TWO MODULES AND TWO COMPONENTS SYSTEM ANALYSIS */00002160
/*
/*          .....                                     */00002170
/*          .....                                     */00002180
/*          .....                                     */00002190
/*          .....                                     */00002200
/*          .....                                     */00002210
/*          .....                                     */00002220
/*          .....                                     */00002230
/*          .....                                     */00002240
/*          .....                                     */00002250
/*          .....                                     */00002260
/*          .....                                     */00002270
/*          .....                                     */00002280
/*          .....                                     */00002290
2  DCL (A(128),B(128),C(128),STHREL,AVSM,AA  ) FLOAT DEC(16); 00002300
3  DCL (TOT,TOT2,VAR,SD,SYSVEC(1000),TIME,MODREL,STMCN) FLOAT DEC(16);00002310
4  DCL (NMOD,NMOD,NPATH,NTERM,SINUM,J,X,NSTRM,M,L,L ) FIXED BIN(15);00002320
5  DCL (COEF(1000) FIXED BIN(4),SOEF(500) FIXED BIN(4); 00002330
6  DCL (IS,IT,NCOMS,NSTAT,NSTAT,M  ) FIXED BIN(15);00002340
7  DCL (MINPTH(128),TERMS(3500)  ) BIT(128) VAR;00002350
8  DCL (SMINP(128),STERM(500)  ) BIT(128) VAR;00002360
9  DCL ATYPE CHAR(11),TYPE(128) BIT(1),UNIT CHAR(5),EQID CHAR(16); 00002370
10 DCL SYSD CHAR(79),ATYP CHAR(11); 00002380
11 DCL NARG FIXED BIN(31); 00002390
12 DCL I(2) 28,1241,821 28,128),RELMO(128),RMDL(128)IFLOAT DEC(16);00002400
13 DCL INCOM(128),NST(128),NTAM(500) ) FIXED BIN(15);00002410
14 DCL TYPE2( 28,128) BIT(1),EQID(128) CHAR(6),ATYP(128) CHAR(11);00002420

```

SYMT

```

/*          TCDF ( 28,128 ) FIXED BIN(4), TTAM( 28,128 ) BIT(128) VAR; 00002430
15 AGNSON PROFILE (SYS) GO TO FINIR; 00002440
16 AVSP = 0.; TOT = 0.; TOT2 = 0.; 00002450
17 EQID=SYS; ATYP= ' '; 00002460
21 CALL INPUT (ATYP,NCOM,NMOD,NPATH,SINUM,SYSID,TIME,UNIT,NARG); 00002470
22 AA=NARG(1); 00002480
23 IF (NMOD=0) THEN GO TO MODULE; 00002490
24 CALL INPUT2 (NCOM,NPATH,TYPE,A,B,MINPTH); 00002500
25 CALL REANREL (NCOM,A,B,TYPE,C(1),ATYP); 00002510
26 CALL NLINE (SYSID,NMOD,NCOM,NPATH,ATYP,SINUM); 00002520
27 CALL NISIN (NCOM,A,B,TYPE,C(1),EQID,ATYP); 00002530
28 CALL EGEN (COEF,MINPTH,NCOM,NPATH, NTERM,TERMS); /* EQUATION DATA */00002540
29 CALL EOUT (ATYP,COEF,MINPTH,NCOM,NPATH,NTERM,TERMS,EQID,NMOD,ATYP); 00002550
30 CALL COMPUTE (C(1),COEF,NCOM,NTERM,TERMS,STHREL); 00002560
31 PUT FILE(SYSPRINT) EDIT ('SPARC52 SYSTEM SIMULATION ROUTINE') 00002570
/*          (PAGE,SKIP(3),A); 00002580
32 IF ATYP = 'U' THEN STHREL=1.-STHREL; 00002590
33 STHC=STHDL; 00002600
34 PUT FILE(SYSPRINT) EDIT (' SYSTEM RELIABILITY CALCULATED FROM ', 00002610
/*          'MEAN COMPONENT RELIABILITIES IS ',STHREL,'; SYSTEM ', 00002620
/*          'RELIABILITY IS ',1.-STHREL(1)SKIP(5),A,A,FILE(6),A,A,FILE(6)); 00002630
/*          'REL RELIABILITY IS ',1.-STHREL(1)SKIP(5),A,A,FILE(6),A,A,FILE(6)); 00002640
/*          'REL RELIABILITY IS ',1.-STHREL(1)SKIP(5),A,A,FILE(6),A,A,FILE(6)); 00002650
35 DO IS = 1 TO SINUM; 00002660
36 CALL DATAGEN (A,B,NCOM,TYPE,C(1),ATYP); 00002670
37 CALL COMPUTE (C(1),COEF,NCOM,NTERM,TERMS,STHREL); /*STH RELIABILITY */00002680
38 IF ATYP = 'U' THEN STHREL=1.-STHREL; 00002690
39 SYSVEC(15)=STHREL; 00002700
40 AVSP = AVSP + STHREL / SINUM; 00002710
41 TOT = TOT + STHREL; 00002720
42 TOT2 = TOT2 + STHREL*STHREL; /* END SIMULATION */00002730
43 END; GO TO SORTSTAT; 00002740
/*          SYSTEM WITH MODULES 00002750
/*          ..... 00002760
/*          ..... 00002770
45 MODULE=NCOMS=NCOM; 00002780
46 NSTAT=NPATH; 00002790
47 CALL INPUT3 (SMINP,NSTAT); 00002800
48 CALL NLINE (SYSID,NMOD,NCOM,NPATH,ATYP,SINUM); 00002810
49 CALL EGEN (SOEF,SMINP,NCOMS,NSTAT,NSTRM,STERM); 00002820
50 CALL EOUT(ATYP,SOEF,SMINP,NCOMS,NSTAT,NSTRM,STERM,EQID,NMOD,ATYP); 00002830
51 DO L=1 BY 1 TO NMOD; 00002840
52 CALL INPUT4 (NCOM,NSTAT,TYPE,A,B,MINPTH,ATYP,EQID); 00002850
53 DO J=1 TO MCM; 00002860
54 TYPE2(L,J) = TYPE(L,J); 00002870
55 A2(L,J) = A(J); 00002880
56 B2(L,J) = B(J); 00002890
57 ENDO; /* NCOM */ 00002900
58 MCM(1)=NCOM; 00002910
59 EQID(1)=EQID; 00002920

```

STAT

```

60      ATYP1(L) = ATYP1      00002920
61      NST1(L) = NST1      00002930
62      CALL EGEN (COEF,MINPTH,MCOM,NSTAT,NTERM,TERMS); 00002940
63      NTRM(L)=NTERM;      00002950
64      DO M=1 TO NTERM;      00002960
65          TCOF(L,M)=COEF(M); 00002970
66          TTRM(L,M)=TERMS(M); 00002980
67      ENDO; /* NTERM */    00002990
68      CALL EOUT(ATYPE,COEF,MINPTH,MCOM,NSTAT,NTERM,TERMS,EQID,MMOD,ATYP1); 00003000
69      CALL REANREL (MCOM,A,B,TYPE,CREL,ATYP1); 00003010
70      CALL COMPUTE (CREL,COEF,MCOM,NTERM,TERMS,RMDL(L)); 00003020
71      IF ATYPE='R' & ATYP='U' THEN RMDL(L)=1.-RMDL(L); 00003030
72      IF ATYPE='U' & ATYP='R' THEN RMDL(L)=1.-RMDL(L); 00003040
73      CALL HISINF (MCOM,A,B,TYPE,CREL,EQID,ATYP1); 00003050
74      ENDO; /* MCOM */    00003060
75      PUT FILE(SYSPRINT) SKIP(5); 00003070
76      CALL COMPUTE (RMDL,DOEF,MCOM,NSTRM,STERN,STHREL); 00003080
77      PUT FILE(SYSPRINT) EDIT ('SPARCS 1: SYSTEM SIMULATION ROUTINE') 00003090
78      (PAGE,SKIP(3),A); 00003100
79      IF ATYPE = 'U' THEN STHREL=L.-STHREL; 00003110
80      STNCR=STHREL; 00003120
81      PUT FILE(SYSPRINT) EDIT (' SYSTEM RELIABILITY CALCULATED FROM ', 00003130
82      'MEAN COMPONENT RELIABILITIES IS ',STHREL,', SYSTEM ', 00003140
83      'UNRELIABILITY IS ',L.-STHREL);SKIP(5),A,A,F18.6),A,A,F18.6); 00003150
84      DO IS=1 TO SIMNUM; 00003160
85          OC=M=1 TO NMMD; 00003170
86          MCOM=MCOM(M); 00003180
87          DO J=1 TO NCOM; 00003190
88              A(J) = AZIN(J); 00003200
89              B(J)=BZIN(J); 00003210
90              TYPE(J)=TYPEZIN(J); 00003220
91          ENDO; /* NCOM */ 00003230
92          CALL DATAGEN (A,B,MCOM,TYPE,CREL,ATYP1(M)); 00003240
93          DO M=1 TO NTRM(M); 00003250
94              COEF(M) = TCOF(M,M); 00003260
95              TERMS(M)=TTRM(M,M); 00003270
96          ENDO; /* NTRM(M) */ 00003280
97          CALL COMPUTE (CREL,COEF,MCOM,NTRM(M),TERMS,MODREL); 00003290
98          IF ATYPE='U' & ATYP1(M)='R' THEN MODREL=L.-MODREL; 00003300
99          IF ATYPE='R' & ATYP1(M)='U' THEN MODREL=L.-MODREL; 00003310
100         RELMOD(M) = MODREL; 00003320
101         ENDO; /* NMMD */ 00003330
102         CALL COMPUTE (RELMOD,DOEF,MCOM,NSTRM,STERN,STHREL); 00003340
103         IF ATYPE = 'U' THEN STHREL=L.-STHREL; 00003350
104         SYSVEC(L)=STHREL; 00003360
105         AVSP = AVSM * STHREL / SIMNUM; 00003370
106         TOT = TOT + STHREL; 00003380
107         TOT2 = TOT2 + STHREL*STHREL; 00003390
108     ENDO; /* END SIMULATION WITH MODULES */ 00003400

```

STAT

```

106 SORTSTAT; 00003410
107 CALL SORT (SIMNUM,SYSVEC); 00003420
108 CALL STATSIMNUM,SYSVEC,AVSM,ATYPE,TIME,UNIT,TOT,TOT2,STNCR); 00003430
109 PUT FILE(SYSPRINT) PAGE; 00003440
110 GO TO AGN; 00003450
/* 00003460
/* 00003470
/* 00003480
110 INPUT1: PROC (ATYPE,MCOM,NMOD,NPATH,SIMNUM,SYSID,TIME,UNIT,NARG); 00003490
/* 00003500
/* THE INPUT1 PROCEDURE READS IN THE DATA FOR THE SYSTEM
/* IDENTIFICATION.
/* ATYPE - ANALYSIS TYPE (RELIABILITY FOR R, UNRELIABILITY FOR U)
/* NARG - SEED FOR RANDOM NUMBER GENERATION
/* MCOM - NUMBER OF COMPONENTS IN SYSTEM.
/* NMMD - NUMBER OF MODULES IN SYSTEM.
/* NPATH - NUMBER OF SYSTEM MINIMAL STATES.
/* SIMNUM - NUMBER OF SIMULATION DESIRED.
/* SYSID - SYSTEM IDENTIFICATION.
/* TIME - MISSION TIME.
/* UNIT - THE UNIT OF TIME MEASUREMENT.
/* 00003510
/* 00003520
/* 00003530
/* 00003540
/* 00003550
/* 00003560
/* 00003570
/* 00003580
/* 00003590
/* 00003600
/* 00003610
111 DCL (MCOM,NMOD,NPATH,SIMNUM) ) FIXED BIN(15); 00003620
112 DCL INARG ) FIXED BIN(15); 00003630
113 DCL ITIME ) FLOAT DEC(16); 00003640
114 DCL ATYPE CHAR (4); UNIT CHAR(4); 00003650
115 DCL SYSID CHAR (4); 00003660
116 GET FILE (SYSINI) EDIT (SYSID) (COL(1),A179); /* READ CARD 1 00003670
117 GET FILE (SYSINI) EDIT (SIMNUM,NARG,TIME) 00003680
/* (COL(1),F(4),R(1),F(9),R(1),F(4)); 00003690
118 GET FILE (SYSINI) LIST (NMOD,MCOM,NPATH); /*NEXT 2 READ CARD 3 00003700
119 GET FILE (SYSINI) EDIT (ATYPE,UNIT) (COL(14),A(1),A(5)); 00003710
120 RETURN; 00003720
121 END INPUT1; 00003730
/* 00003740
/* 00003750
122 INPUT2: PROC (MCOM,NPATH,TYPE,A,B,MINPTH); 00003760
/* 00003770
/* THIS INPUT2 PROCEDURE READS IN THE HISTORICAL DATA FOR COMPONENTS
/* AND MINIMAL STATES IN BINARY REPRESENTATION FOR THE COMPUTATION
/* OF SYSTEM RELIABILITY WITHOUT MODULES.
/* TYPE(1) - TYPE OF COMPONENT (SEE DATAGEN PROCEDURE).
/* A(1) - NUMBER OF OBSERVED SUCCESSES (SEE PORT IN DATAGEN).
/* B(1) - NUMBER OF OBSERVED FAILURES (SEE FAIL IN DATAGEN).
/* MINPTH(1) - MINIMAL STATES IN BINARY REPRESENTATION.
/* 00003780
/* 00003790
/* 00003800
/* 00003810
/* 00003820
/* 00003830
/* 00003840
/* 00003850
123 DCL (MCOM,NPATH,1) ) FIXED BIN(15); 00003860
124 DCL (A(1),B(1)) ) FLOAT DEC (6); 00003870
125 DCL MINPTH(1) BIT (1) VAR = TYPE(1) BIT(1); 00003880
126 GET FILE(SYSINI) LIST (TYPE(1),A(1),B(1)) DO 1=1 TO MCOM; 00003890

```

STMT

```

127 GET FILE (SYSIN) LIST ((MINPTH) DO I=1 TO NPATH);          00003900
128 RETURN;                                                    00003910
129 END INPUT2;                                                  00003920
/*                                                            00003930
/*                                                            00003940
130 INPUTS: PROC (SMINP,NSTAT);                                00003950
/*                                                            00003960
/* INPUTS READ IN THE MINIMAL STATES (SMINP) FOR SYSTEM WHICH WILL 00003970
/* HAVE THE MODULES IN IT.                                     00003980
/*                                                            00003990
131 DCL SMINP(*) BIT(*) VAR, NSTAT FIXED BIN(15);             00004000
132 DCL (I)                                                            00004010
133 GET FILE (SYSIN) LIST ((SMINP(I) DO I=1 TO NSTAT));       00004020
134 RETURN;                                                       00004030
135 END; /* INPUT3 */                                           00004040
/*                                                            00004050
/*                                                            00004060
136 INPUTS: PROC (NCOM,STATES,TYPE,A,B,MINPTH,ATYP,EQID);      00004070
/*                                                            00004080
/* THE INPUTS PROCEDURE READS IN THE DATA FOR THE MODULE 00004090
/* IDENTIFICATION.                                           00004100
/* ATYP - ANALYSIS TYPE (RELIABILITY FOR R, UNRELIABILITY FOR U) 00004110
/* EQID - MODULE IDENTIFICATION                             00004120
/* NCOM - NUMBER OF COMPONENTS IN SYSTEM.                   00004130
/* STATES - NUMBER OF SYSTEM MINIMAL STATES.                00004140
/*                                                            00004150
137 DCL (NCOM,STATES) FIXED BIN(15), (A(*),B(*)) FLOAT DEC(4); 00004160
138 DCL MINPTH(*) BIT(*) VAR, EQID CHAR(*), ATYP CHAR(*), TYPE(*) 00004170
139 BIT(*);                                                       00004180
140 GET FILE (SYSIN) EDIT (ATYP,EQID) (COL(1),A(1),B(1));      00004190
141 GET FILE (SYSIN) LIST (NCOM,STATES);                       00004200
142 GET FILE (SYSIN) LIST ((TYPE(I),A(I),B(I) DO I=1 TO NCOM)); 00004210
143 GET FILE (SYSIN) LIST ((MINPTH(I) DO I=1 TO STATES));       00004220
144 RETURN;                                                       00004230
145 END; /* INPUT4 */                                           00004240
/*                                                            00004250
/*                                                            00004260
146 MEANREL: PROC (NCOM,A,B,TYPE,ACR,ATYP);                    00004270
/*                                                            00004280
/* A COMPUTATION PROCEDURE FOR THE MEAN RELIABILITY OF COMPONENT 00004290
/* BASED UPON THE HISTORICAL DATA OF EACH COMPONENT RELIABILITY. 00004300
/*                                                            00004310
147 DCL (NCOM,I) FIXED BIN(15), (A(*),B(*),ACR(*)) FLOAT DEC(4); 00004320
148 TYPE(*) BIT(*) ATYP CHAR(*);                                00004330
149 DO I=1 TO NCOM;                                              00004340
150 IF TYPE(I)='R' THEN ACR(I)=(A(I)+1.)/(A(I)+B(I)+2.1);      00004350
151 ELSE ACR(I)=(A(I)+1.)/(A(I)+2.1)+((B(I)+1.)/2.1);          00004360
152 IF ATYP = 'U' THEN ACR(I) = 1. - ACR(I);                   00004370
153 END;                                                         00004380

```

STMT

```

152 RETURN;                                                    00004390
153 END MEANREL;                                                00004400
/*                                                            00004410
/*                                                            00004420
154 HDLINE: PROC (SYSID,NMOD,NCOM,NPATH,ATYP,SIMNUM);           00004430
/*                                                            00004440
/* PRINT OUT THE MAJOR HEADINGS FOR KEY VARIABLES AND SYSTEM ID. 00004450
/*                                                            00004460
155 DCL SYSID CHAR (*), ATYP CHAR (*), STA CHAR(*) VAR;         00004470
156 DCL (NCOM,NMOD,NPATH,SIMNUM,NC)                             00004480
157 IF ATYP='R' THEN STA='PATHS';                                00004490
158 ELSE STA='CUTS';                                             00004500
159 PUT FILE(SYSPRINT) EDIT ('* S P A R C S *');               00004510
160 (PAGE,A) ('SIMULATION PROGRAM FOR THE ANALYSIS OF THE ', 00004520
161 'RELIABILITY OF COMPLEX SYSTEMS') (SKIP(1),A,A) ('SYSTEM ', 00004530
162 'IDENTIFICATION',SYSID) (SKIP(5),A,A,X(13),A) 00004540
163 ('NUMBER OF SIMULATIONS ',SIMNUM) (SKIP(1),A,X(14),F(3)) 00004550
164 ('NUMBER OF MODULES ',NMOD) (SKIP(1),A,X(17),F(3)) 00004560
165 ('NUMBER OF COMPONENTS ',NCOM) (SKIP(1),A,X(14),F(3)) 00004570
166 ('NUMBER OF MINIMAL ',STA,NPATH) (SKIP(1),A,X(12),F(3)); 00004580
167 IF ATYP = 'R' THEN DO;                                       00004590
168 PUT FILE(SYSPRINT) EDIT ('TYPE OF ANALYSIS',RELIABILITY') 00004600
169 (SKIP(1),A,X(21),A);                                         00004610
170 END;                                                         00004620
171 ELSE DO;                                                      00004630
172 PUT FILE(SYSPRINT) EDIT ('TYPE OF ANALYSIS',UNRELIABILITY') 00004640
173 (SKIP(1),A,X(21),A);                                         00004650
174 END;                                                         00004660
175 RETURN;                                                       00004670
176 END; /* HDLINE */                                           00004680
/*                                                            00004690
/*                                                            00004700
177 MISINF: PROC (NCOM,A,B,TYPE,ACR,EQID,ATYP);               00004710
/*                                                            00004720
/* MISINF PRINTS THE HISTORICAL INFORMATION FOR EACH 00004730
/* COMPONENT EITHER IN A SYSTEM OR IN MODULES.              00004740
/*                                                            00004750
178 DCL ATYP CHAR(*);                                           00004760
179 DCL (A(*),B(*),ACR(*))                                00004770
180 DCL TYPE(*) BIT(*),EQID CHAR(*),ID CHAR(13) INIT ('') VAR; 00004780
181 DCL (NCOM,NC)                                                00004790
182 IF EQID = 'SYS' THEN ID='SYSTEM';                             00004800
183 ELSE ID='MODULE';                                             00004810
184 PUT FILE(SYSPRINT) EDIT ('HISTORICAL INFORMATION FOR EACH ', 00004820
185 'COMPONENT IN ',ID,ISATP(5),A,A,A) ('COMPONENT',TYPE 00004830
186 'SUCCESS (RELIABILITY)', FAILURES ',PRIOR DISTRIBUTION') 00004840
187 (SKIP(2),A,X(7),A,X(13),A,X(17),A,X(14),A) 00004850
188 ('EQUIVALENT MISSIONS(GAMMA)',MEAN') (SKIP(1),COL(35),A, 00004860
189 X(26),A);                                                    00004870

```

STMT

```

176 IF ATYPE = 'R' THEN DO 1 00004880
177 DO NC=1 TO NCON: 00004890
178 IF TYPE(NC)='1'B THEN DO: 00004900
179 PUT FILE(SYSPRINT) EDIT (NC,'ATTRIBUTE(BETA)',A(NC),B(NC),ACR(NC)) 00004910
180 1-ACR(NC) 1-ACR(NC) 00004920
181 P(18,5)11: END: 00004930
182 ELSE DO: 00004940
183 PUT FILE(SYSPRINT) EDIT (NC,'TIME-TO-FAILURE(GAMMA)',A(NC),B(NC), 00004950
184 ACR(NC) 1-ACR(NC) 1-ACR(NC) 00004960
185 X(15),P(18,5)11: END: 00004970
186 END: 00004980
187 END: 00004990
188 ELSE DO: 00005000
189 DO NC=1 TO NCON: 00005010
190 IF TYPE(NC)='1'B THEN DO: 00005020
191 PUT FILE(SYSPRINT) EDIT (NC,'ATTRIBUTE(BETA)',A(NC),B(NC), 00005030
192 1-ACR(NC) 1-ACR(NC) 00005040
193 1-ACR(NC) 1-ACR(NC) 00005050
194 P(18,6)11: END: 00005060
195 ELSE DO: 00005070
196 PUT FILE(SYSPRINT) EDIT (NC,'TIME-TO-FAILURE(GAMMA)',A(NC),B(NC), 00005080
197 1-ACR(NC) 1-ACR(NC) 1-ACR(NC) 00005090
198 X(15),P(18,6)11: END: 00005100
199 END: 00005110
200 END: 00005120
201 RETURN: 00005130
202 END: /MISSING= / 00005140
/* 00005150
/* EGEN:PROC(COEF,NINPTH,NCON,NPATH,NTERM,TERMS): 00005160
/* ***** 00005170
/* ***** 00005180
/* THE PROBABILITY EQUATIONS ARE ENTIRELY GENERATED IN THIS EGEN=00005190
/* PROCEDURE USING POINCARÉ'S METHOD (INCLUSION-EXCLUSION). FOR A 00005200
/* SYSTEM HAVING N MINIMAL STATES, THE PROBABILITY EQUATION HAS A 00005210
/* MAXIMUM OF 2**N-1 TERMS, HOWEVER, THE EQUATION GENERATED BY EGEN 00005220
/* HAS ONLY A FRACTION OF THE MAXIMUM NUMBER OF TERMS, BECAUSE OF: 00005230
/* CANCELLATION OF DUPLICATE TERMS. AFTER EACH MINIMAL STATE IS 00005240
/* INTRODUCED AND COMBINED WITH THE PREVIOUSLY GENERATED TERMS. 00005250
/* TO FORM POSSIBLE NEW TERMS THE ACCUMULATION PROCESS IS PERFORMED. 00005260
/* TERMS THAT HAVE ZERO COEFFICIENTS ARE REMOVED BEFORE THE NEXT 00005270
/* MINIMAL STATE IS INTRODUCED. 00005280
/* 00005290
/* VARIABLES: COEF - COEFFICIENTS IN PROBABILITY EQUATION. 00005300
/* TERMS- TERMS OF PROBABILITY EQUATION IN BIT STRING. 00005310
/* ***** 00005320
199 DCL COEF (4) FIXED BIN(4): 00005330
200 DCL NINPTH (4) BIT (4) VAR: 00005340
201 DCL I1,I2,I3,I4,I5,I6,I7,KK1,KDUP,NSUB,NDUP,INC2)FIXED BIN(15):00005350
202 DCL INCON, NPATH,NTERM ) FIXED BIN(15):00005360

```

STMT

```

203 DCL TERMS (4) BIT (4) VAR: 00005370
204 TERMS(1)=NINPTH(1):COEF(1)=1: /* 1ST 3 TERMS OF PROB. EQU. 00005380
205 IF NPATH=1 THEN DO: 00005390
206 NTERM=1: RETURN: END: 00005400
207 TERMS(2)=NINPTH(2): COEF(2)=1: 00005410
208 TERMS(3)=NINPTH(3) : NINPTH(2): 00005420
209 COEF(3)=1: 00005430
210 ATERM=3: 00005440
211 IF NPATH=2 THEN GO TO ENDEQ: 00005450
212 NSUB=4: 00005460
213 DO I1 = 3 TO NPATH: /* DO LOOP1, REMAINING TERMS 00005470
214 TERMS(NSUB)=NINPTH(I1): 00005480
215 COEF(NSUB)=1: 00005490
216 NSUB=NSUB+1: 00005500
217 DO I2 = 1 TO NTERM: /* DO LOOP2 00005510
218 TERMS(NSUB)=NINPTH(I1) : TERMS(I2): 00005520
219 COEF(NSUB)=COEF(I2): /* DETERMINE COEFFICIENT 00005530
220 NSUB=NSUB+1: 00005540
221 END: /* ENDO LOOP2 00005550
222 NDUP=0: /* ACCUMULATE DUPLICATE TERMS 00005560
223 INC2=NSUB-1: 00005570
224 DO I3=1 TO INC2: 00005580
225 DO I4=3 TO I3-1-NDUP: 00005590
226 IF TERMS(I4)=TERMS(I3-NDUP) THEN GO TO ENDI4: 00005600
227 COEF(I4)=COEF(I4) + COEF(I3-NDUP): 00005610
228 IF I3-NDUP=NSUB-1 THEN GO TO SUB: 00005620
229 DO I5=I3-NDUP TO INC2-1-NDUP: 00005630
230 TERMS(I5)=TERMS(I5+1): 00005640
231 COEF(I5)=COEF(I5+1): 00005650
232 END: 00005660
233 SUB: NSUB=NSUB-1: 00005670
234 NDUP=NDUP+1: 00005680
235 GO TO ENDI3: 00005690
236 ENDI4: END: 00005700
237 ENDI3: END: 00005710
238 KDUP=0: /* REMOVE TERMS WITH ZERO COEFFICIENTS 00005720
239 KK1=NSUB-1: 00005730
240 DO I6=3 TO KK1: 00005740
241 IF COEF(I6-KDUP)=0 THEN GO TO ENDI6: 00005750
242 IF I6-KDUP=NSUB-1 THEN GO TO SUB: 00005760
243 DO I7=I6-KDUP TO KK1-1-KDUP: 00005770
244 TERMS(I7)=TERMS(I7+1): 00005780
245 COEF(I7)=COEF(I7+1): 00005790
246 END: 00005800
247 NSUB=NSUB-1: 00005810
248 KDUP=KDUP+1: 00005820
249 ENDI6: END: 00005830
250 NTERM=NSUB-1: 00005840
251 END: /* ENDO LOOP1 00005850

```

STMT

```

254 ENDOE: END EOGEM:                                00005860
/*                                                    */00005870
/*                                                    */00005880
257 EQUT: PROC (ATYPE,COEF,MINPTH,NCOM,NPATH,NTERM,TERMS,EQID,NMDO,ATYP): 00005890
/******00005900*****
/* PRINT OUT THE SYSTEM RELIABILITY EQUATION BY USING THE BINARY */00005910
/* VECTOR TERMS(*) AND COEFFICIENT OF COEF(*) FROM THE FUNCTION */00005920
/* PROCEDURE EUGEN. */00005930
/******00005940*****
258 DCL (K4,K5,K6,K7,LEN,LENG,NCOM,MINP,NTERM,NPATH,NK) FIXED BIN(15); 00005950
259 DCL SIGN CHAR(3) VAR, STATE CHAR(5) VAR,NMDO FIXED BIN(15); 00005960
260 DCL (CHAR1,CHAR2,MINP ) CHAR(120) VAR;00005970
261 DCL (MINPTH(*) BIT(*) VAR, TERMS (*) BIT (*) VAR: 00005980
262 DCL COEF (*) FIXED BIN( 4), ATYPE CHAR(1),EQID CHAR(4),ATYP 00005990
CHAR(1); 00006000
263 DCL KOMP(128) CHAR(3) VARYING INITIAL(' ','2','3', 00006010
'4','5','6','7','8','9','10','11','12','13','14','15','16', 00006020
'17','18','19','20','21','22','23','24','25','26','27', 00006030
'28','29','30','31','32','33','34','35','36','37','38', 00006040
'39','40','41','42','43','44','45','46','47','48','49', 00006050
'50','51','52','53','54','55','56','57','58','59','60', 00006060
'61','62','63','64','65','66','67','68','69','70','71', 00006070
'72','73','74','75','76','77','78','79','80','81','82', 00006080
'83','84','85','86','87','88','89','90','91','92','93', 00006090
'94','95','96','97','98','99','100','101','102','103', 00006100
'104','105','106','107','108','109','110','111','112', 00006110
'113','114','115','116','117','118','119','120','121', 00006120
'122','123','124','125','126','127','128') STATIC; 00006130
264 DCL C0 CHAR(1), C1 CHAR(2), C2 CHAR(3), C3 CHAR(4); 00006140
265 DCL MOOSY(128) CHAR(3) VARYING INITIAL(' ','B','C', 00006150
'0','1','2','3','4','5','6','7','8','9','A','B','C','D', 00006160
'E','F','G','H','I','J','K','L','M','N','O','P','Q', 00006170
'R','S','T','U','V','W','X','Y','Z','A1','B1','C1','D1', 00006180
'E1','F1','G1','H1','I1','J1','K1','L1','M1','N1','O1', 00006190
'P1','Q1','R1','S1','T1','U1','V1','W1','X1','Y1','Z1', 00006200
'A2','B2','C2','D2','E2','F2','G2','H2','I2','J2','K2', 00006210
'L2','M2','N2','O2','P2','Q2','R2','S2','T2','U2','V2', 00006220
'W2','X2','Y2','Z2','A3','B3','C3','D3','E3','F3','G3', 00006230
'H3','I3','J3','K3','L3','M3','N3','O3','P3','Q3','R3', 00006240
'S3','T3','U3','V3','W3','X3','Y3','Z3','A4','B4','C4', 00006250
'D4','E4','F4','G4','H4','I4','J4','K4','L4','M4','N4', 00006260
'O4','P4','Q4','R4','S4','T4','U4','V4','W4','X4') STATIC; 00006270
266 IF EQID = 'SYS' THEN DO: 00006280
267 IF ATYPE = 'R' THEN DO: 00006290
268 IF NPATH=1 THEN STATE='PATH' ; 00006300
269 ELSE STATE='PATHS'; 00006310
270 CO='R'; C1='R' ; C2='R' ; C3='R' ; 00006320
271 END: 00006330
272 ELSE DO: 00006340
273 IF NPATH=1 THEN STATE='CUT' ;

```

STMT

```

277 ELSE STATE='CUTS' ; 00006350
278 CO='U'; C1='U' ; C2='U' ; C3='U' ; 00006360
282 END: 00006370
283 PUT FILE(SYSPRINT) EDIT ('SPARC52: EQUATION GENERATION ROUTINE') 00006380
(PAGE,SKIP(3),A1); 00006390
284 END: 00006400
285 ELSE DO: 00006410
286 IF ATYP = 'R' THEN DO: 00006420
287 IF NPATH=1 THEN STATE='PATH' ; 00006430
288 ELSE STATE='PATHS'; 00006440
289 CO='R'; C1='R' ; C2='R' ; C3='R' ; 00006450
293 END: 00006460
294 ELSE DO: 00006470
295 IF NPATH=1 THEN STATE='CUT' ; 00006480
296 ELSE STATE='CUTS' ; 00006490
297 CO='U'; C1='U' ; C2='U' ; C3='U' ; 00006500
301 END: 00006510
302 END: 00006520
303 IF 'EQID='SYS' THEN PUT FILE(SYSPRINT) EDIT ('THE 'NPATH, 00006530
' MINIMAL ',STATE,' FOR ',MODULE 'EQID);SKIP(3),A,F(3), 00006540
A,A,A,A,A); ELSE 00006550
304 PUT FILE (SYSPRINT) EDIT('THE 'NPATH,' MINIMAL ',STATE,' FOR' 00006560
' SYSTEM '); (SKIP(3),A,F(3),A,A,A,A,SKIP(2)); 00006570
305 PUT FILE(SYSPRINT) SKIP(2); 00006580
306 L5:DO K4=1 TO NPATH; 00006590
307 MINP=1; 00006600
308 MINP=C1; 00006610
309 L6:DO K5=1 TO NCOM; /* OUTPUT FOR MINIMAL STATES */ 00006620
310 IF SUBSTR(MINPTH(K4),K5,1)='1' THEN 00006630
IF EQID='SYS' + C NMDO = 0 THEN MINP=MINP|| MOOSY(K5)||','; 00006640
ELSE MINP=MINP|| KOMP(S(K5))||','; 00006650
311 END: 00006660
312 /* L6 */ 00006670
313 MINP=LENGTH(MINP); 00006680
314 SUBSTR(MINP,MINP,1)='>'; 00006690
315 PUT FILE (SYSPRINT) EDIT (MINP) (SKIP(1),COL(1),A); 00006700
316 END: /* L5 */ 00006710
317 PUT FILE (SYSPRINT) EDIT ('NUMBER OF TERMS IN EQUATION: ',NTERM) 00006720
(SKIP(2),COL(2),A,F(4),D); 00006730
318 PUT FILE (SYSPRINT) SKIP(2); 00006740
319 CHAR1=''; /* DETERMINATION OF COMPONENT SYMBOLS FOR OUTPUT */ 00006750
320 CHAR2=C0; 00006760
321 CHAR1=CHAR1||EQID; 00006770
322 CHAR2=CHAR2||' = ' ; 00006780
323 L7:DO K6=1 TO NTERM; 00006790
324 IF COEF(K6) > 0 THEN SIGN='+' ; 00006800
325 ELSE SIGN='-' ; 00006810
326 IF K6 = 1 THEN GO TO AG; 00006820
327 CHAR2=CHAR2||SIGN; 00006830
328 CHAR1=CHAR1||' ' ;

```

STMT

```

329 AG: DO K7 = 1 TO NCOM;                                00006840
330 IF SUBSTR(TEAMS(K7),K7,1) = '0'B THEN GO TO L50;      00006850
331 IF EODIM*SYS + 6*NCOD = 0 THEN DO;                    00006860
332 CHAR1=CHAR1||MODSY(K7)||' ';                          00006870
333 LEN6=LENGTH(KOMP5(K7));                               00006880
334 END;                                                    00006900
335 ELSE DO;                                                00006910
336 CHAR1=CHAR1||KOMP5(K7) ||' ';                          00006920
337 LEN6=LENGTH(KOMP5(K7));                               00006930
338 END;                                                    00006940
339 IF LEN6=1 THEN CHAR2=CHAR2||C1;                        00006950
340 ELSE IF LEN6=2 THEN CHAR2=CHAR2||C2;                  00006960
341 ELSE CHAR2=CHAR2||C3;                                  00006970
342 LEN=LENGTH(CHAR2);                                     00006980
343 IF LEN>112 & LEN<120 THEN DO;                          00006990
344 IF K7 = NCOD THEN CHAR2=CHAR2||'0';                   00007000
345 PUT FILE (SYSPRINT) EDIT (CHAR2) IS4(IP(2),COL(3),A); 00007010
346 PUT FILE (SYSPRINT) EDIT (CHAR1) (COL(4),A);          00007020
347 LEN=0;                                                  00007030
348 CHAR1='';                                              00007040
349 CHAR2='';                                              00007050
350 END;                                                    00007060
351 ELSE DO;                                                00007070
352 GO TO L50;                                             00007080
353 END;                                                    00007090
354 L50:END; /* AG */                                       00007100
355 END; /* L7 */                                           00007110
356 PUT FILE (SYSPRINT) EDIT (CHAR2) (SKIP(2),COL(3),A); 00007120
357 PUT FILE (SYSPRINT) EDIT (CHAR1) (COL(4),A);          00007130
358 RETURN;                                                00007140
359 END;                                                    00007150
/*                                                    00007160
/*                                                    00007170
360 COMPUTE: PROC (REL,CDEF,NCOD,NTERM,TERMS,SYSREL);      00007180
/*-----*/                                              00007190
/* PROCEDURE COMPUTE CALCULATES VALUES OF THE RELIABILITY OF 00007200
/* EACH SYSTEM BY USING THE PROBABILITY EQUATION GENERATED BY THE 00007210
/* PROCEDURE EODEN.                                       00007220
/*-----*/                                              00007230
/* VARIABLES: SYSREL - SYSTEM RELIABILITY.              00007240
/*-----*/                                              00007250
361 DCL (NCOD,NTERM,KA,KB)                                00007260
362 DCL (SYSREL,REL)                                        00007270
363 DCL (BADD,DREL,OSYSREL)                               00007280
364 DCL (TERMS) BIT (1) VAR;                               00007290
365 DCL COEF (1) FIXED BINARY;                           00007300
366 SYSREL=0.1;                                           00007310
367 DO KA = 1 TO NTERM;                                    00007320
368 BADD=1.0;                                             00007330

```

STMT

```

369 DO KB = 1 TO NCOM;                                    00007330
370 IF SUBSTR(TEAMS(KA),KA,1) = '1'B THEN GO TO FIN;      00007340
371 DREL=REL(KB);                                           00007350
372 BADD=BRGD*DREL;                                         00007360
373 FIN: END;                                               00007370
374 SYSREL=OSYSREL+BADD*CDEF(KA);                          00007380
375 END;                                                    00007390
376 SYSREL=OSYSREL;                                         00007400
377 END COMPUTE;                                           00007410
/*                                                    00007420
/*                                                    00007430
378 DATAGEN: PROCEDURE (PORT,FAIL,NCOD,TYPE,REL,ATYPE);    00007440
/*-----*/                                              00007450
/* THIS FUNCTION PROCEDURE OBTAINS VALUES OF COMPONENT 00007460
/* RELIABILITY BY CALLING THE BETA(CABTA) OR GAMMA(RGAMA) 00007470
/* RANDOM VARIATES GENERATOR CORRESPONDING TO EACH      00007480
/* CHARACTER OF COMPONENT.                               00007490
/*-----*/                                              00007500
/* VARIABLES: FAIL - NUMBER OF ACCUMULATED FAILURES    00007510
/* IV - INDICATOR FOR MTBF COMPUTATION                  00007520
/* NCOD - NUMBER OF COMPONENTS IN A SYSTEM              00007530
/* RELE=1 - VALUE OF COMPONENT RELIABILITY              00007540
/* TYPE - 0: FOR TIME-TO-FAILURE COMPONENT              00007550
/* 1: FOR SUCCESS-FAILURE COMPONENT                     00007560
/* PORT - NO. OF SUCCESSES FOR TYPE 1                   00007570
/* NO. OF TESTUNITS FOR TYPE 0                           00007580
/* REQUIRED FUNCTION PROCEDURES - CABTA, RGAMA           00007590
/*-----*/                                              00007600
379 DCL (REL(1),PORT(1),FAIL(1),AA,B,TEMP)                00007610
380 DCL (NCOD,IO)                                          00007620
381 DCL TYPE(1) BIT (1),ATYPE CHAR(1);                   00007630
382 DO IO=1 TO NCOD;                                      00007640
383 IF TYPE(IO) = '1'B THEN GO TO BTVR;                   00007650
384 ELSE IF TYPE(IO) = '0'B THEN GO TO GMYR;              00007660
385 PUT FILE (SYSPRINT) LIST ('TYPE,PORT,FAIL DESIGNATED IN ERROR'); 00007670
386 STOP;                                                  00007680
387 BTVR: AA=PORT(IO) + 1.; /* SUCCESS-FAILURE COMPONENT RELIABILITY 00007690
388 B = FAIL(IO) + 1.;                                     00007700
389 REL(IO) = CABTA(AA,B);                                 00007710
390 IF ATYPE = 'U' THEN REL(IO) = 1. - REL(IO);           00007720
391 GO TO NXTT;                                            00007730
392 GMYR: AA=FAIL(IO) + 1.; /* TIME-TO-FAILURE COMPONENT RELIABILITY 00007740
393 B = 1./PORT(IO)+1.;                                   00007750
394 TEMP = RGAMA(AA) + 0.1;                               00007760
395 REL(IO) = EXP (-TEMP);                                 00007770
396 IF ATYPE = 'U' THEN REL(IO) = 1. - REL(IO);          00007780
397 NXTT:END;                                              00007790
398 END DATAGEN;                                           00007800
/*                                                    00007810

```

STMT

```

399 /* CABYA: PROC (A,B) RETURNS (FLOAT DEC(6)); */00007820
/****** */00007830
/* GENERATES RANDOM DEViates FROM THE BETA DISTRIBUTION WITH */00007840
/* PARAMETERS EQUAL TO A AND B RESPECTIVELY. */00007850
/* THE PROBABILITY DENSITY IS PROPORTIONAL TO */00007860
/*  $\text{EXP}(-X) \cdot (1-X)^{(B-1)}$ . */00007870
/* THE VALUES OF A AND B MUST EACH BE  $\geq 1.0$ . */00007880
/* IF THE VALUES OF A, OR B, OR BOTH, ARE  $\leq 1.0$  THEN THE METHOD */00007890
/* USED IS DIRECT MAPPING OF UNIFORM PSEUDO-RANDOM NUMBERS USING */00007900
/* THE INVERSE OF THE CUMULATIVE DISTRIBUTION FUNCTION. */00007910
/* THE METHOD USED IF THE VALUES OF A AND B ARE BOTH  $\geq 1.0$  IS */00007920
/* REJECTION FROM A CAUCHY DENSITY TRUNCATED TO BE NONZERO ONLY IN */00007930
/* THE INTERVAL (0,1). PARH AND PARC ARE SAFETY FACTORS ON THE */00007940
/* HEIGHT AND CURVATURE OF THE CAUCHY DENSITY AT THE MODE. */00007950
/* J. P. CHANDLER AND K. A. LEE, OKLAHOMA STATE UNIVERSITY 1977 */00007960
/****** */00007970
/****** */00007980
/****** */00007990
400 DCL PARH FLOAT DEC(6) INIT(1.1); */00008000
401 DCL PARC FLOAT DEC(6) INIT(1.1); */00008010
402 DCL PI FLOAT DEC(6) INIT(3.14159); */00008020
403 DCL A1SAV FLOAT DEC(6) INIT(1.1); */00008030
404 DCL B1SAV FLOAT DEC(6) INIT(1.1); */00008040
405 DCL Z FIXED BIN(31) INIT(0); */00008050
406 DCL (A1,B1,ALCNST,ALPA,XMODE,XMODEC,CL,A,B,U,T,GCL) FLOAT DEC(6); */00008060
407 DCL (FBL,DT,BJ,BL) */00008070
408 IF A = 1. & B = 1. THEN RETURN (RANF(Z)); */00008080
409 A1=A-1.; */00008090
410 B1=B-1.; */00008100
/* CHECK FOR ILLEGAL VALUES OF A AND B. */00008110
/* IF A1 < 0. & B1 < 0. THEN GO TO L2; */00008120
/* IF B1=0. THEN RETURN(RANF(Z))*((1./A)); */00008130
/* ELSE IF A1=0. THEN RETURN(1.-RANF(Z))*((1./B)); */00008140
/* TEST TO SEE IF WE MUST RECOMPUTE THE */00008150
/* VALUES OF CONSTANTS. */00008160
414 IF A1=A1SAV & B1=B1SAV THEN GO TO L1; */00008170
415 A1SAV=A1; */00008180
416 B1SAV=B1; */00008190
417 XMODE=A1/(A1+B1); */00008200
418 XMODEC=1.-XMODE; */00008210
419 ALCNST=ALGAMA1*(A1+B1)-ALGMA1A1-ALGMA1B1; */00008220
420 ALPA=PARC*SORT(2.*XMODE*XMODEC/(A1+B1)); */00008230
421 CL= LOG(PARH)*((ALPA)+ALCNST+A1) LOG(XMODE)+B1 LOG(XMODEC); */00008240
422 B1=ATANH(XMODE/ALPA); */00008250
423 BU=ATAN(XMODEC/ALPA); */00008260
/* NOW USE REJECTION FROM THE CAUCHY DIST. */00008270

```

STMT

```

424 L1:DT=TANH(BL*(BU-BL)*RANF(Z))*ALPA; */00008310
425 T=XMODE*DT; */00008320
426 IF T < 0. & T > 1. THEN GO TO L1; */00008330
427 GCL=CL+ LOG(ALPA/(ALPA+DT))+DT*(2./PI); */00008340
428 FBL=ALCNST+A1* LOG(T)+B1* LOG(1.-T); */00008350
429 IF FBL > GCL THEN GO TO L2; */00008360
430 L11:U=RANF(Z); */00008370
431 IF U < 0. THEN GO TO L11; */00008380
432 IF GCL+LOG(U) > FBL THEN GO TO L1; */00008390
433 RETURN(T); */00008400
434 L2:PUT FILE(SYSPRINT) LIST (' ERROR IN SUBROUTINE CABYA ',A,B, */00008410
/* XMODE,ALCNST,ALPA,CL,T,GCL,FBL); */00008420
435 STOP; */00008430
436 END; */00008440
/* */00008450
/* */00008460
/* */00008470
437 ALGAMA: PROC (XX) RETURNS (FLOAT DEC(6)); */00008480
/****** */00008490
/* COMPUTES THE DOUBLE PRECISION NATURAL LOGARITHM OF THE GAMMA */00008500
/* FUNCTION OF A GIVEN DOUBLE PRECISION ARGUMENT. */00008510
/****** */00008520
438 DCL (ZZ,TERM,RZZ) FLOAT DEC (14); */00008530
439 DCL (XX,DNG) FLOAT DEC (6), ERROR CHAR(1) INIT('0'); */00008540
440 IF XX <= 1.E10 */00008550
/* THEN IF XX <= 1.E-09 */00008560
/* THEN DO ; */00008570
/* ERROR='2' PUT FILE(SYSPRINT) DATA (ERROR) SKIP(2); */00008580
441 DNG=-1.E75; */00008590
442 GO TO S20; */00008600
443 ELSE DO ; */00008610
444 TERM=1.E0; */00008620
445 IF ZZ > 0 AND < OR = TO 1.E+10 */00008630
/* THEN DO ; */00008640
446 IF ZZ <= 18.E3 */00008650
/* THEN DO ; */00008660
447 TERM=TERM*ZZ; */00008670
448 GO TO S10; */00008680
449 ELSE DO ; */00008690
450 ZZ=1.E0/ZZ; */00008700
451 GO TO S10; */00008710
452 ELSE DO ; */00008720
453 RZZ=1.E0/ZZ**2; */00008730
454 DNG=(ZZ-0.5E0)*LOG(1-ZZ)-ZZ*(0.914938533204672E0 */00008740
/* -LOG(1+1.E0/ZZ)+(.833333333333333E-01 */00008750
/* -14.2241-2.7777777777777E-02*(RZZ* */00008760
/* (-7.9565073450793E-37*(RZZ* */00008770
/* (-5.95238095238095E-03))))); */00008780
455 GO TO S20; */00008790
456 END; */00008800
457 S10: */00008810
458 S20: */00008820

```

STMT

[illegible]

SYNOPSIS

```

=====
//GENERATES RANDOM NORMAL DEVIATES.... RANDOM NUMBERS FROM A GAUSSIAN //00009290
//DISTRIBUTION WITH ZERO MEAN AND UNIT VARIANCE. //00009300
//G, NARGSGLA AND T, A. BRAT, S.I.A.M. REVIEW 6 (1964) 260. //00009320
//FOR A RANDOM NUMBER FROM THE GAUSSIAN DISTRIBUTION WITH MEAN VALUE //00009330
//EQUAL TO 'MEAN' AND STANDARD DEVIATION EQUAL TO 'SIGMA', USE... //00009340
// BNG=AREAN+SIGNA*GAUS(IUMPI) //00009350
// //00009360
// J. P. CHANDLER, COMPUTING & INFORMATION SCIENCE, O S U //00009370
// CODED IN PL/I BY K. L. LEE. //00009380
// //00009390
=====
497 DCL LOG10 FIXED BIN(31) INIT(0); //00009400
498 DCL NARGA FIXED BIN(31) INIT(0); //00009410
499 DCL NDUMY FIXED BIN(31); //00009420
500 DCL I,ABX,X,EX,FAC,G,GAUS,SUMSQ,VA,VB,X,Y,TMP 1 FLOAT DEC(16); //00009430
501 DCL I,ARJUMP,B //00009440
502 GAUS = 0; //00009450
503 NARGA=NARG; //00009460
504 RJUMP=RAINF(NARG); //00009470
505 IF RJUMP < .1362 THEN GO TO L20; //00009480
506 A=I*JUMP-.136217;86381 //00009490
// //00009500
// DEFEAT THE IDIOTIC ENR 64 OPTIMIZATION. =//00009510
// //00009520
507 B=RAINF(NARG); //00009530
508 TMP=A+B+RAINF(NARGA)-1.5; //00009540
509 GAUS=TMP*2.; //00009550
510 GO TO L10; //00009560
511 L20: IF RJUMP < .0255 THEN GO TO L40; //00009570
512 A=I*JUMP-.025517;1107; //00009580
513 GAUSPL=5*1+A+RAINF(NARGA)-1.3; //00009590
514 GO TO L10; //00009600
515 L40: IF RJUMP < .00269797961 THEN GO TO L110; //00009610
516 X=6.*RAINF(NARG);-3.; //00009620
517 Y=358*RAINF(NARGA); //00009630
518 EX=17.49731196*EXPE(-.5*XX*2); 1 //00009640
519 ABX=ABS(X); //00009650
520 IF ABX > 1. THEN GO TO L70; //00009660
521 G=X-4.735702*G*Y3.-X*2)-2.15787544*(1.5-ABX); //00009670
522 GO TO L90; //00009680
523 L70: EX=X-2.38785163*Y3.-ABX*2); //00009690
524 IF ABX > 1.5 THEN GO TC L90; //00009700
525 G=X-2.15787544*(1.5-ABX); //00009710
526 L90: IF Y > G THEN GO TO L150; //00009720
527 GAUS=X; //00009730
528 GO TO L150; //00009740
529 L110:VA=2.*RAINF(NARGA)-1.; //00009750
530 VB=2.*RAINF(NARGA)-1.1 //00009760
531 SUMSQ=VA*VA+VB*VB; //00009770
532 IF SUMSQ > 1. THEN GO TO L110; //00009780

```

STMT

```

533 IF SUMSO <= 0. THEN GO TO L110; 00009780
534 PAC$ORT((19.-2.*LOG(SUMSO))/SUMSO); 00009790
535 GAUSS-VARFAC; 00009800
536 IF ABS(GAUSS) < .3 THEN GO TO L110; 00009810
537 L110:RETURN(GAUSS); 00009820
538 END; 00009830
/* 00009840
/* 00009850
/* 00009860
539 (NOFIXEDOVERFLOW) : RAND : PROC (NARG) RETURNS (FLOAT DEC (6)); 00009870
/* THIS FUNCTION GENERATES PSEUDO-RANDOM NUMBERS, UNIFORMLY 00009880
/* DISTRIBUTED ON (0,1). THIS VERSION IS FOR THE IBM 360. 00009890
/* METHOD... COMPOSITE OF THREE MULTIPLICATIVE CONGRUENTIAL GENERATOR 00009910
/* C. MARSAGLIA AND T. A. BRAY, COMM. ACM 11 (1968) 757. 00009920
/* IF RAND IS CALLED WITH NARG=0, THE NEXT RANDOM NUMBER IS RETURNED. 00009930
/* IF RAND IS CALLED WITH NARG=-1, THE GENERATOR IS RE-INITIALIZED. 00009940
/* USING IABS(2*NARG+1) AND THE FIRST RANDOM NUMBER FROM THE NEW 00009950
/* SEQUENCE IS RETURNED. 00009960
/* 00009970
/* CODED IN PL/I BY WILLIAM SCOTT DAVIS FROM A FORTRAN VERSION BY 00009980
/* J. P. CHANDLER, COMPUTER SCIENCE DEPT., OKLAHOMA STATE UNIVERSITY. 00009990
/* 00010000
***** 00010010
540 DCL K FIXED BINARY(31) INITIAL(7654321) STATIC; 00010020
541 DCL L FIXED BINARY(31) INITIAL(7654321) STATIC; 00010030
542 DCL M FIXED BINARY(31) INITIAL(7654321) STATIC; 00010040
543 DCL N FIXED BINARY(31) STATIC INITIAL(2826291); 00010050
544 DCL ML FIXED BINARY(31) STATIC INITIAL(34921); 00010060
545 DCL MM FIXED BINARY(31) STATIC INITIAL(65541); 00010070
546 DCL MARG FIXED BINARY(31); 00010080
547 DCL MFIRST BIT(1); 00010090
548 DCL IJ,KLM,N(128),NDIV,M 1 FIXED BINARY(31) STATIC; 00010100
549 DCL I,RAN,RDIV 1 FLOAT DEC(6) STATIC; 00010110
550 IF MARG = 0 THEN DO; /* RE-INITIALIZE USING MARG. 00010120
551 KLM = ABS(2 * MARG + 1); 00010130
552 K=L*M = KLM; 00010140
553 END; 00010150
554 ELSE DO; 00010160
555 IF MFIRST THEN GO TO SKP; 00010170
556 END; 00010180
557 MFIRST = '0'B; /* INITIALISE THE ROUTINE. 00010190
558 NDIV = 16777216; 00010200
559 RDIV = 32768.0 = 65536.0; 00010210
560 DO J = 1 TO 128; /* FILL THE TABLE. 00010220
561 K = R * M; 00010230
562 NEJJ = K; 00010240
563 END; 00010250
564 SKP: L = L * ML; /* COMPUTE THE NEXT RANDOM NO. 00010260

```

STMT

```

565 J = 1 + ABS(I) / NDIV; 00010270
566 P = M * M; 00010280
567 NR = ABS(NEJJ) + L * M; 00010290
568 RAN = FLOAT(NR) / RDIV; 00010300
569 K = K + M; /* REFILL THE J-TH PLACE IN THE TABLE 00010310
570 NEJJ = K; 00010320
571 RETURN(RAN); 00010330
572 END RAND; 00010340
/* 00010350
/* 00010360
573 SORT:PROC(IN.X); 00010370
/* 00010380
/* 00010390
/* SORTING PROCEDURE ON THE VALUES OF THE SYSTEM RELIABILITY BY 00010400
/* USING SHELL SORTING METHOD. 00010410
/* 00010420
/* HIBBARD T. M. AN EMPIRICAL STUDY OF MINIMAL STORAGE SORTING. 00010430
/* COMM. ACM 6 (MAY,1963), 206. 00010440
/* 00010450
***** 00010460
574 DCL IN,M,I,J 1 FIXED BINARY(31); 00010470
575 DCL XI(1),Y 1 FLOAT DEC(6); 00010480
576 IF M<2 THEN RETURN; 00010490
577 M = M-1; 00010500
578 ONE = M/2; 00010510
579 DO J=1 TO M-M; 00010520
580 Y = XI(J+M); 00010530
581 DO I=J BY -M TO 1; 00010540
582 IF XI(I) > Y THEN GO TO TWO; 00010550
583 XI(M+1) = XI(I); 00010560
584 END; 00010570
585 TWO:XI(I+M) = Y; 00010580
586 END; 00010590
587 IF M<1 THEN GO TO ONE; 00010600
588 RETURN; 00010610
589 END; /* SHELL SORT */ 00010620
/* 00010630
/* 00010640
590 STAT: PROC (SN,SV,AVSN,ATYPE,TIME,UNIT,TOT,TOT2,STMC); 00010650
/* 00010660
/* PROCEDURE STAT COMPUTES THE ESTIMATED SYSTEM MTBF,SYSTEM 00010670
/* RELIABILITY AND MTBF PERCENTILE POINTS USING A SET OF SYSTEM 00010680
/* RELIABILITIES GENERATED BY MONTE CARLO PROCEDURE. 00010690
***** 00010700
591 DCL PCT(11) FLOAT DEC(6) INIT (.05,.1,.2,.25,.5,.75,.8,.9,.95,.975,.99); 00010710
592 DCL EI,SN,IV 1 FIXED BINARY(31); 00010720
593 DCL TIME,FVAL,CVA,SZ,FLOG,TOT,TOT2,SD,VAR,PR 1 FLOAT DEC(6); 00010730
594 DCL UNIT CHAR(1),ATYPE1 CHAR(1),ATYPE CHAR(1),STMC1 FLOAT DEC(6); 00010740

```

STMT

```

595 DO I=1 TO 11: VAL(I)=0.; MTBF(I)=0.; END; 00010740
599 ATYPE1 = 'RELIABILITY'; 00010770
600 IF SN=1 THEN DO; 00010780
601 VAR = 0.; SD=0.; 00010790
603 END; 00010800
604 ELSE DO; 00010810
605 VAR=(TOT2-TOT*TOT/SM)/(SN-1); 00010820
606 SD = SORT(VAR); 00010830
607 END; 00010840
608 PUT FILE(SYSPRINT) EDIT (' AVERAGE SYSTEM RELIABILITY FROM ', 00010850
    SINUM,' MONTE CARLO TRIALS IS ',AVSM,' ; AVERAGE SYSTEM ', 00010860
    'UNRELIABILITY IS ',1.-AVSM) 00010870
    (SKIP(5),A,F(3),A,F(8.6),A,F(8.6)) 00010880
    (' VARIANCE' 00010890
    ' ' ,VAR) (SKIP(2),A,A,F(8.6)) (' STANDARD DEVIATION' 00010900
    ' ' ,SD) (SKIP(2),A,A,F(8.6)) ; 00010910
609 IF TIME = 0 THEN 00010920
DO:MTBFPCR=TIME/LOG(STHCR); 00010930
611 MTBA=TIME/LOG(AVSM); 00010940
612 PUT FILE(SYSPRINT) EDIT ('THE MISSION TIME IS ',TIME,UNIT) 00010950
    (SKIP(5),COL(6),A,F(8.3),X(2),A) ('THE ESTIMATED SYSTEM MTBF' 00010960
    'BASED UPON MEAN COMPONENT RELIABILITIES IS ',MTBPCR) 00010970
    (SKIP(2),COL(6),A,A,E(15.8))('THE ESTIMATED SYSTEM MTBF ', 00010980
    'BASED UPON MEAN SYSTEM RELIABILITY ',SINUM,' MONTE CARLO ', 00010990
    'TRIALS IS ',MTBA) (SKIP(2),COL(6),A,A,E(15.8)) 00011000
    (ATYPE1,'MTBF ') (SKIP(3), 00011010
    COL(24),A,COL(49),A) ('PERCENTILE','PERCENTILE','PERCENTILE') 00011020
    (COL(4),A,COL(25),A,COL(44),A) ('POINTS','POINTS') (COL(27), 00011030
    A,COL(48),A); 00011040
613 END; 00011050
614 ELSE DO; 00011060
615 PUT FILE (SYSPRINT) EDIT ('PERCENTILE','PERCENTILE') (SKIP(3),00011070
    COL(5),A,COL(29),A) ('POINTS') (COL(33),A); 00011080
616 END; 00011090
/* 00011100
617 DO I=1 TO 11; 00011110
618 VAL(I)=SN*PCT(I)*.5; 00011120
619 IV=FIXED(IVAL(I)); 00011130
620 FVAL=FLOAT(FV(I)); 00011140
621 IF FVAL = VAL(I) THEN DO; 00011150
622 VAL(I)=VAL(I)-FVAL; 00011160
623 IF IV=0 THEN DO; 00011170
624 SZR=SV(1)*2.-SV(2); 00011180
625 CVA=SV(2)-SV(1); 00011190
626 VAL(I)=CVA*VAL(I); 00011200
627 VAL(I)=SZR*VAL(I); 00011210
628 END; 00011220
629 ELSE DO; 00011230
630 IF IV=SN THEN DO; 00011240

```

STMT

```

631 CVA=SV(IV)-SV(IV-1); 00011250
632 END; 00011260
633 ELSE DO; 00011270
634 CVA=SV(IV+1)-SV(IV); 00011280
635 END; 00011290
636 VAL(I)=CVA*VAL(I); 00011300
637 VAL(I)=SV(IV)+VAL(I); 00011310
638 END; 00011320
639 END; 00011330
640 ELSE DO; 00011340
641 VAL(I)=SV(IV); 00011350
642 END; 00011360
643 IF TIME = 0 THEN DO; 00011370
644 MTBF(I)=TIME/LOG(VAL(I)); 00011380
645 PUT FILE(SYSPRINT) EDIT (PCT(I)*100., 'PERCENT',VAL(I),MTBF(I), 00011390
    UNIT) (SKIP(2),COL(1),F(7.1),COL(10),A,COL(26),F( 8.4),X(9), 00011400
    E(15.8),X(2),A); 00011410
646 END; 00011420
647 ELSE DO; 00011430
648 PUT FILE (SYSPRINT) EDIT (PCT(I)*100., 'PERCENT',VAL(I)) 00011440
    (COL(2),F(7.1),A,COL(30),F(8.4)); 00011450
649 END; 00011460
650 EXIT;END; 00011470
651 END; /* STAT =/ 00011480
/* 00011490
/* 00011500
/* 00011510
652 FINIS; 00011520
END; 00011530

```