HEWLETT-PACKARD

HP-67/HP-97

Users' Library Solutions

Reliability/QA

INTRODUCTION

In an effort to provide continued value to it's customers, Hewlett-Packard is introducing a unique service for the HP fully programmable calculator user. This service is designed to save you time and programming effort. As users are aware, Programmable Calculators are capable of delivering tremendous problem solving potential in terms of power and flexibility, but the real genie in the bottle is program solutions. HP's introduction of the first handheld programmable calculator in 1974 immediately led to a request for program **solutions** — hence the beginning of the HP-65 Users' Library. In order to save HP calculator customers time, users wrote their own programs and sent them to the Library for the benefit of other program users. In a short period of time over 5,000 programs were accepted and made available. This overwhelming response indicated the value of the program library and a Users' Library was then established for the HP-67/97 users.

To extend the value of the Users' Library, Hewlett-Packard is introducing a unique service—a service designed to save you time and money. The Users' Library has collected the best programs in the most popular categories from the HP-67/97 and HP-65 Libraries. These programs have been packaged into a series of low-cost books, resulting in substantial savings for our valued HP-67/97 users.

We feel this new software service will extend the capabilities of our programmable calculators and provide a great benefit to our HP-67/97 users.

A WORD ABOUT PROGRAM USAGE

Each program contained herein is reproduced on the standard forms used by the Users' Library. Magnetic cards are not included. The Program Description I page gives a basic description of the program. The Program Description II page provides a sample problem and the keystrokes used to solve it. The User Instructions page contains a description of the keystrokes used to solve problems in general and the options which are available to the user. The Program Listing I and Program Listing II pages list the program steps necessary to operate the calculator. The comments, listed next to the steps, describe the reason for a step or group of steps. Other pertinent information about data register contents, uses of labels and flags and the initial calculator status mode is also found on these pages. Following the directions in your HP-67 or HP-97 **Owners' Handbook and Programming Guide,** "Loading a Program" (page 134, HP-67; page 119, HP-97), key in the program from the Program Listing I and Program Listing II pages. A number at the top of the Program Listing indicates on which calculator the program was written (HP-67 or HP-97). If the calculator indicated differs from the calculator you will be using, consult Appendix E of your **Owner's Handbook** for the corresponding keycodes and keystrokes converting HP-67 to HP-97 keycodes and vice versa. No program conversion is necessary. The HP-67 and HP-97 are totally compatible, but some differences do occur in the keycodes used to represent some of the functions.

A program loaded into the HP-67 or HP-97 is not permanent—once the calculator is turned off, the program will not be retained. You can, however, permanently save any program by recording it on a blank magnetic card, several of which were provided in the Standard Pac that was shipped with your calculator. Consult your **Owner's Handbook** for full instructions. A few points to remember:

The Set Status section indicates the status of flags, angular mode, and display setting. After keying in your program, review the status section and set the conditions as indicated before using or permanently recording the program.

REMEMBER! To save the program permanently, **clip** the corners of the magnetic card once you have recorded the program. This simple step will protect the magnetic card and keep the program from being inadvertently erased.

As a part of HP's continuing effort to provide value to our customers, we hope you will enjoy our newest concept.

TABLE OF CONTENTS

Program Description I

Program Title RELIABILITY: INTRA-CLASS CORRELATION

Contributor's Name Hewlett-Packard
Address 1000 N.E. Circle Blvd.
City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables, etc. Let the scores (measures) X_{ij} represent the j-th subject's score on the i-th test (measurement). In the ANOVA model $X_{ij} = \mu + a_j + e_{ij}$, μ the mean "true" measure over all subjects, a_j the deviation of the j-th subject from that mean, and e_{ij} the error in test i on the j-th subject, the reliability of the set of tests is the ratio $\rho_I = \sigma_A^2/\sigma_X^2$, of true-difference variance to observed-score variance. This ratio is estimated by the formula

$$r_I = \frac{MS_{Bet} - MS_{With}}{MS_{Bet} + (c-1)MS_{With}},$$

where MS_{Bet} is the between mean squares, MS_{With} the within mean squares, and c is a factor dependent on sample size given by

$$c = \frac{1}{J-1}\left[\sum n_j - \frac{\sum n_j^2}{\sum n_j}\right]$$

where J is the number of subjects, n_j the number of test scores for subject j. Standard formulas are used for the mean squares, and the ANOVA F-ratio is computed as a by-product of the main program.

Operating Limits and Warnings This estimate is based on the ANOVA random-effects model, and violations of its assumptions (e.g., normal distribution of the a_j, homogeneity of variances) should be held to a minimum for an accurate estimate. Winer (op. cit.) and other texts fully explain these assumptions and possible effects of departures. Most ill effects are minimized by use of equal n_j's, for all $j = 1, 2, \ldots, J$.

Program Description II

Sketch(es)

Sample Problem(s) The following data represent the scores of three subjects on repeated measurements of the same attribute. Compute the intra-class correlation (reliability) estimate and the ANOVA F.

j \ i	1	2	3	4	5	6
1	10	8	5	12	14	11
2	6	9	8	13		
3	14	13	10	17	16	

Solution(s) $r_I = 0.36$; $F = 3.79$

Keystrokes:		Outputs:
[f][CLREG] 10 [A] 8 [A]····· 11[A] [B]		
6 [A] 9 [A]···· 13[A] [B]		
14 [A] 13 [A]···· 16 [A] [B]		
[C]	→	0.36
[R/S]	→	3.79

Reference(s) Winer, B. J., Statistical principles in experimental design, pp. 165, 283-287, McGraw-Hill, 1971.

This program is a translation of the HP-65 Users' Library Program # 03102A submitted by James M. Price.

User Instructions

INTRA-CLASS CORRELATION				
Σ+	Subj	r_I		

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize		f	REG	
3	(Repeat for i=1, 2,..., n_j) Enter	X_{ij}	A		i
4	(After all n_j Steps #3; repeat for				
	j=1, 2,..., J)		B		0.00
5	Compute r_I		C		r_I
6	(Optional) Compute ANOVA F		R/S		F
	(degrees of freedom are found by:				
	RCL, 6, 1, - and RCL, 4, RCL, 6, -)				
	For new data, go to step 2.				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	accum. X
002	ST+7	35-55 07	
003	X^2	53	
004	ST+2	35-55 02	accum. X^2
005	RCL8	36 08	
006	1	01	
007	+	-55	
008	STO8	35 08	increment count
009	RTN	24	
010	*LBLB	21 12	
011	RCL7	36 07	
012	ST+1	35-55 01	
013	X^2	53	
014	RCL8	36 08	$(\Sigma X)^2$
015	÷	-24	recall cell size
016	ST+3	35-55 03	$(\Sigma X)^2/n$
017	LSTX	16-63	
018	ST+4	35-55 04	accum. n_j
019	X^2	53	
020	ST+5	35-55 05	accum. n_j^2
021	1	01	
022	ST+6	35-55 06	
023	CLX	-51	
024	STO7	35 07	
025	STO8	35 08	
026	RTN	24	
027	*LBLC	21 13	
028	RCL3	36 03	
029	RCL1	36 01	
030	X^2	53	
031	RCL4	36 04	
032	÷	-24	
033	-	-45	
034	RCL6	36 06	
035	1	01	
036	-	-45	df between
037	÷	-24	MS between
038	STO7	35 07	→ R7
039	RCL2	36 02	
040	RCL3	36 03	
041	-	-45	
042	RCL4	36 04	
043	RCL6	36 06	
044	-	-45	df within
045	÷	-24	MS within
046	STO8	35 08	→ R8
047	RCL6	36 06	
048	1	01	
049	-	-45	
050	1/X	52	
051	RCL4	36 04	
052	RCL5	36 05	
053	RCL4	36 04	
054	÷	-24	
055	-	-45	
056	×	-35	
057	STO9	35 09	c
058	RCL7	36 07	
059	RCL8	36 08	
060	-	-45	
061	RCL7	36 07	
062	RCL9	36 09	
063	1	01	
064	-	-45	
065	RCL8	36 08	
066	×	-35	
067	+	-55	
068	÷	-24	
069	R/S	51	r_I
070	RCL7	36 07	
071	RCL8	36 08	
072	÷	-24	F
073	R/S	51	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n 2	

REGISTERS

0	1	2	3	4	5	6	7	8	9
	$\Sigma\Sigma X_{ij}$	$\Sigma\Sigma X_{ij}^2$	$\Sigma n_j \bar{X}_j^2$	Σn_j	Σn_j^2	J	used	used	c
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title SPECIFICATION COMPLIANCE from LIMITS and REGRESSION ANALYSIS

Contributor's Name Hewlett-Packard Company

Address 1000 N.E. Circle Boulevard

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables

$$X_i = X_o + \Delta x$$

$$X_{i+1} = X_i + \Delta x$$

$$Y_i = A + B X_i$$

$$Z_L = \frac{Y_i - L}{S} \; ; \; P_L = f(Z_L) \quad \text{Note 1}$$

$$Z_u = \frac{U - Y_i}{S} \; ; \; P_u = f(Z_u) \quad \text{Note 1}$$

$$Y_u = U - ZS \; ; \; X_u = \frac{Y_u - A}{B}$$

$$Y_L = L + ZS \; ; \; X_L = \frac{Y_L - A}{B}$$

A = intercept value
B = slope
S = standard deviation
L = lower specification limit
U = Upper specification limit
Y = ordinate
X = abscissa
Δx = change in X value
Z = standard normal deviate
subscripts:
- o = original value
- i = any other value
- u = upper limit
- L = lower limit

NOTE 1 : P_L and P_u are the probability of meeting the lower or upper specification limits respectively. They are found from a table of the normal probability distribution at the value of Z_L or Z_u in question.

Operating Limits and Warnings

Program Description II

Sketch(es)

i	X_i	Y_i	Z_L	Z_u	P_L	P_u
0	15.00	42.50	-1.88	9.38	.030	1.000
1	20.00	50.00	0.00	7.50	.500	1.000
2	25.00	57.50	1.88	5.63	.970	1.000
3	30.00	65.00	3.75	3.75	1.000	1.000
4	35.00	72.50	5.63	1.88	1.000	.970
5	40.00	80.00	7.50	0.00	1.000	.500
6	45.00	87.70	9.38	-1.88	1.000	.030

NOTE:
obtain P_L and P_u from table of normal distribution

Sample Problem(s) The following information is obtained from a regression analysis for a linear equation: A = 20; B = 1.5; S = 4.0. What are the probabilities of meeting specification limits of L = 50 and U = 80 as X varies from 15.0 to 45.0 in steps of 5.0? What are the X values at the specification limits and the x and y values at the lower and upper 90% confidence limits?

Solution(s) Insert program: 20 ↑, 1.5 ↑, 4.0 ↑, 15.0 , [f] [A] 50 ↑, 80 ↑, 5.0 [R/S] [A] y_o = 42.50; [B] Z_L = -1.88; [C] Z_u = 9.38; [D] X_1 = 20.00; [A] y_1 = 50.00 [B] Z_L = 0.00; [C] Z_u = 7.50; [D] X_L = 25.00 . . . etc. to complete the table shown under sketches.

For the x values at the specification limits [CLX] [E] Y_L = 50.00; [R/S] X_L = 20.00; [f] [STF] [1] [CLX] [E] Y_u = 80.00; [R/S] X_u = 40.00

For 90% limits [f][CLF][1]

[GTO][1][R/S][E] Y_{L90} = 55.13; [R/S] X_{L90} = 23.42; [f] [STF] [1] [GTO] [1] [R/S] [E] Y_{u90} = 74.87; [R/S] X_{u90} = 36.58

Reference(s) This program is a translation of the HP - 65 Users' Library Program # 03202A submitted by George J. Sellers.

User Instructions

1 SPECIFICATION COMPLIANCE from LIMITS and REGRESSION ANALYSIS 2

Y_i | Z_i | Z_u | X_{i+1} | X,Y, Δt, Z

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter Program				
2	Enter A		↑		
3	B		↑		
4	S		↑		
5	X_o		f	A	
6	L		↑		
7	U		↑		
8	Δx		R/S		
9			A		Y_o
10			B		Z_L
11			C		Z_u
12			D		X_{i+1}
	Repeat 9 through 11 for each new X				
13	for X_L at L		CLX	E	L
14			R/S		X_L
15	for X_u at U		[f][STF][1][CLX]		
16			E		U
17			R/S		X_u
18	for 90% limits		[f][CLF][1][GTO][1]		
19			R/S	E	Y_{L90}
20			R/S		X_{L90}
21			[f][STF][1][GTO][1]		
22			R/S	E	Y_{u90}
23			R/S		X_{u90}
24	for 95% limits substitute GTO2 for GTO1				
	in steps 18 and 21				
25	for 99% limits substitute GTO3 for GTO1				
	in steps 18 and 21				
26	for X_L, Y_L at a given Z, enter Z		[f][CLF][1][E]		X_Z at Z
27			R/S		X_L at Z
28	for X_u, Y_u at a given Z, enter Z		[f][STF][1][E]		Y_u at Z
29					X_L at Z
	Note: when calculating X and Y at U				
	flag 1 must be fSF1; at L flag 1				
	must be f^{-1} SF1.				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLa	21 16 11	
002	STO8	35 08	
003	R↓	-31	
004	STO3	35 03	
005	R↓	-31	
006	STO2	35 02	
007	R↓	-31	
008	STO1	35 01	
009	R/S	51	
010	STO5	35 05	
011	R↓	-31	
012	STO6	35 06	
013	R↓	-31	
014	STO4	35 04	
015	CLX	-51	
016	ENT↑	-21	
017	ENT↑	-21	
018	ENT↑	-21	
019	R/S	51	
020	*LBLA	21 11	
021	RCL8	36 08	
022	RCL2	36 02	
023	×	-35	
024	RCL1	36 01	
025	+	-55	
026	STO7	35 07	
027	R/S	51	
028	*LBLB	21 12	
029	RCL4	36 04	
030	-	-45	
031	RCL3	36 03	
032	÷	-24	
033	R/S	51	
034	*LBLC	21 13	
035	RCL6	36 06	
036	RCL7	36 07	
037	-	-45	
038	RCL3	36 03	
039	÷	-24	
040	R/S	51	
041	*LBLD	21 14	
042	RCL8	36 08	
043	RCL5	36 05	
044	+	-55	
045	STO8	35 08	
046	R/S	51	
047	*LBLE	21 15	
048	STO9	35 09	
049	RCL3	36 03	
050	×	-35	
051	F1?	16 23 01	
052	GTO4	22 04	
053	RCL4	36 04	
054	*LBL5	21 05	
055	+	-55	
056	R/S	51	
057	RCL1	36 01	
058	-	-45	
059	RCL2	36 02	
060	÷	-24	
061	R/S	51	
062	*LBL4	21 04	
063	CHS	-22	
064	RCL6	36 06	
065	GTO5	22 05	
066	*LBL1	21 01	
067	1	01	
068	.	-62	
069	2	02	
070	8	08	
071	1	01	
072	7	07	
073	R/S	51	
074	*LBL2	21 02	
075	2	02	
076	1	01	
077	.	-62	
078	6	06	
079	4	04	
080	5	05	
081	R/S	51	
082	*LBL3	21 03	
083	3	03	
084	2	02	
085	.	-62	
086	3	03	
087	2	02	
088	3	03	
089	7	07	
090	R/S	51	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	2

REGISTERS

0	1	2	3	4	5	6	7	8	9
	A	B	S	L	Δx	U	Y_i	X_i	A

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title PARAMETER ESTIMATION (EXPONENTIAL DISTRIBUTION)

Contributor's Name Hewlett - Packard Company

Address 1000 N.E. Circle Boulevard

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables

Case 1

Let X be the sample mean of a random sample of size n from a truncated exponential distribution with pdf.

$$f(x) = \sigma^{-1} e^{-x/\sigma} / (1 - e^{-x_o/\sigma}) \qquad 0 \leq X \leq X_o$$

The maximum likelihood estimator $\hat{\sigma}$ for σ is the solution of

$$\bar{X} - \hat{\sigma} + X_o (e^{x_o/\hat{\sigma}} - 1)^{-1} = 0$$

Case 2

Let $X_{(1)} < X_{(2)} \ldots < X_{(r)}$ denote the first r order statistics from a random sample of size n from a distribution with pdf.

$$f(x) = \sigma^{-1} \text{EXP } (-(x-\Theta)/\sigma) \qquad \Theta \leq X \leq \infty$$

The minimum variance unbiased estimators for σ and Θ are

$$\sigma^* = (r-1)^{-1} \sum_{j=2}^{r} (n-j) \ (X_{(j+1)} - X_{(j)})$$

$$\Theta^* = X_{(1)} - \sigma^*/n$$

Operating Limits and Warnings In case 1, σ is finite only if $X < X_o/2$. If $X > X_o/2$, then $\hat{\sigma}$ is infinite - this means that the truncated exponential distribution is not a good model for the observations. Program may not work when $\bar{X}$ is very close to $X_o/2$.

Program Description II

Sketch(es)

Sample Problem(s)

CASE 1 $X_o = 5$, $X = 2$

CASE 2 $n = 5$, $r = 4$ $X_{(j)}$, j = 1,--, 4 = 11.12,12.55,13.47,14.58

Solution(s)

CASE 1 $\hat{\sigma} = 4.065$

CASE 2 $\sigma^* = 3.567$, $\Theta^* = 10.407$

Keystrokes:	Outputs:
5 [ENT↑] 2 [A] →	4.065
5 [ENT↑] 4 [ENT↑] 11.12 [B] 12.55 [C] 13.47 [C]	
14.58 [C] [D] →	3.567
[E] →	10.407

Reference(s)

Johnson and Kotz, "Continuous Univariate Distributions - 1", Houghton Mifflin Co., 1970.

This program is a translation of the HP - 65 Users' Library Program # 03652A submitted by Richard Freedman.

User Instructions

1 PARAMETER ESTIMATION (EXPONENT DISTRIBUTION) 2

$\hat{\sigma}$	n, r, X°	$X_{(j)}$	σ^*	Θ^*

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter Program				
	CASE 1				
2		X°	↑		
3	Note: X must be less than $X_0/2$	$\bar{X}$	A		$\hat{\sigma}$
	For new Case 1 go to 2				
	CASE 2				
4		n	↑		
5		r	↑		
6		$X_{(1)}$	B		
7	Repeat 7 for j = 2,3,..., r	$X_{(j)}$	C		j
8			D		σ^*
9			E		Θ^*
	for new Case 2 go to 4				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	Iterate to find
002	STO1	35 01	root of likelihood
003	STO3	35 03	equation
004	R↓	-31	$\sigma \leftarrow \sigma - \Delta\sigma$
005	STO4	35 04	
006	*LBL1	21 01	
007	RCL1	36 01	
008	GSBE	23 15	
009	STO2	35 02	
010	RCL1	36 01	
011	+	-55	
012	GSBE	23 15	
013	RCL2	36 02	
014	-	-45	
015	LSTX	16-63	
016	ENT↑	-21	
017	×	-35	
018	X⇄Y	-41	
019	÷	-24	
020	RCL1	36 01	
021	X⇄Y	-41	
022	-	-45	
023	STO1	35 01	
024	LSTX	16-63	
025	ABS	16 31	
026	EEX	-23	Continue
027	3	03	iterations until
028	CHS	-22	$\lvert\Delta\sigma\rvert < 0.001$
029	X≤Y?	16-35	
030	GTO1	22 01	
031	RCL1	36 01	
032	RTN	24	
033	*LBLE	21 15	Compute
034	ENT↑	-21	likelihood
035	ENT↑	-21	equation
036	RCL4	36 04	
037	X⇄Y	-41	
038	÷	-24	
039	e^x	33	
040	1	01	
041	-	-45	
042	1/X	52	
043	RCL4	36 04	
044	×	-35	
045	-	-45	
046	RCL3	36 03	
047	-	-45	
048	RTN	24	
049	*LBLB	21 12	
050	STO1	35 01	$X_{(1)}$
051	STO5	35 05	last ← $X_{(1)}$
052	R↓	-31	
053	1	01	
054	STO4	35 04	
055	-	-45	
056	STO2	35 02	
057	R↓	-31	
058	STO3	35 03	
059	0	00	
060	STO6	35 06	
061	RTN	24	
062	*LBLC	21 13	
063	RCL5	36 05	
064	X⇄Y	-41	
065	STO5	35 05	
066	-	-45	
067	RCL3	36 03	
068	RCL4	36 04	
069	-	-45	
070	×	-35	S ← S+(n−j)
071	ST-6	35-45 06	($X_{(j)}$ − Last)
072	RCL4	36 04	
073	1	01	
074	+	-55	
075	STO4	35 04	
076	RTN	24	
077	*LBLD	21 14	
078	RCL6	36 06	
079	RCL2	36 02	
080	÷	-24	
081	STO6	35 06	
082	RTN	24	
083	*LBLE	21 15	[Note that label E
084	RCL1	36 01	is used twice
085	RCL6	36 06	intentionally]
086	RCL3	36 03	
087	÷	-24	
088	-	-45	
089	RTN	24	
090			
100			
110			

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	2

REGISTERS

0	1	2	3	4	5	6	7	8	9
	$\hat{\sigma}$, $X_{(1)}$	Temp, r−1	$\bar{X}$, n	j	Last	S			Used
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title LOWER LIMIT OF RELIABILITY - BINOMIAL DISTRIBUTION

Contributor's Name Hewlett - Packard Company

Address 1000 N.E. Circle Boulevard

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables

$$(1 - \gamma) = \sum_{j=o}^{x} \left[\frac{N!}{j!(N-j)!}\right] P^j (1 - P)^{N-j}$$

where N = total number of items tested

j = number of items failed

γ = confidence level (in decimal form .XX)

P = probability of failure

(1-P) = reliability = $R_{L.X}$

$$\alpha = \frac{(1-\gamma) - (1-\gamma)\ \text{calculated}}{(1 - \gamma)}$$ allowable error

Operating Limits and Warnings $N \leq 69$

$.50 < \gamma < .99$ for most cases γ will not work if outside this range.

Program Description II

Sketch(es)

Sample Problem(s) A) Twenty rocket motors are fired with one failure; what is the demonstrated reliability at the lower 90% confidence level?

B) Fifty components are tested at 1 1/2 times their normal rated loading; what is the maximum number of failures that can be obtained and still demonstrate a .87 reliability at a 95% confidence level?

C) What is the reliability of 1 failure out of 15 tests of the 90% confidence level calculated to four decimal places ($\alpha \leq .001$).

Solution(s)

A) 20 [↑], 1 [A] [B] → 0.82

B) 50 [↑], 1 [A], .95 [C] 0.91

50 [↑], 2 [A], .95 [C] 0.88

50 [↑], 3 [A], .95 [C] 0.85

only 2 failures can be obtained

C) 15 [↑], 1 [A], .001 [STO] [7] [B] → 0.7645

Reference(s) This program is a translation of the HP - 65 Users' Library Program # 03820A submitted by George J. Sellers.

User Instructions

1 LOWER LIMITS of RELIABILITY - BINOMIAL DISTRIBUTION 2

Enter N ↑, j	$R_{L.90}$	R_{LX}		

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter Program				
2	Enter N		↑		
3	Enter j		A		
4	for $R_{L.90}$		B		$R_{L.90}$
5	for $R_{L.X}$ Enter .X		C		$R_{L.X}$
6	for α < .1 Enter α after step 3 α		STO	7	
	go to step 4 or 5				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	
002	CLRG	16-53	
003	STOI	35 46	
004	STO2	35 02	
005	R↓	-31	
006	STO1	35 01	
007	.	-62	
008	1	01	
009	STO7	35 07	
010	CF1	16 22 01	
011	STO5	35 05	
012	STO3	35 03	
013	CLX	-51	
014	ENT↑	-21	
015	ENT↑	-21	
016	ENT↑	-21	
017	R/S	51	
018	*LBLC	21 13	
019	1	01	
020	-	-45	
021	CHS	-22	
022	STO5	35 05	
023	*LBLB	21 12	
024	1	01	
025	RCL3	36 03	
026	-	-45	
027	STO4	35 04	
028	RCL2	36 02	
029	STOI	35 46	
030	*LBL1	21 01	
031	1	01	
032	RCL1	36 01	
033	N!	16 52	
034	RCLI	36 46	
035	N!	16 52	
036	÷	-24	
037	RCL1	36 01	
038	RCLI	36 46	
039	-	-45	
040	N!	16 52	
041	÷	-24	
042	RCL3	36 03	
043	RCLI	36 46	
044	Y^X	31	
045	×	-35	
046	RCL4	36 04	
047	RCL1	36 01	
048	RCLI	36 46	
049	-	-45	
050	Y^X	31	
051	×	-35	
052	ST+6	35-55 06	
053	DSZI	16 25 46	
054	SF1	16 21 01	
055	RCLI	36 46	
056	1	01	
057	CHS	-22	
058	X≠Y?	16-32	
059	GTO1	22 01	
060	RCL7	36 07	
061	RCL6	36 06	
062	RCL5	36 05	
063	-	-45	
064	RCL5	36 05	
065	÷	-24	
066	ABS	16 31	
067	X≤Y?	16-35	
068	GTO2	22 02	
069	RCL6	36 06	
070	RCL5	36 05	
071	+	-55	
072	2	02	
073	÷	-24	
074	RCL5	36 05	
075	÷	-24	
076	1	01	
077	+	-55	
078	RCL3	36 03	
079	×	-35	
080	2	02	
081	÷	-24	
082	STO3	35 03	
083	0	00	
084	STO6	35 06	
085	GTOB	22 12	
086	*LBL2	21 02	
087	RCL4	36 04	
088	R/S	51	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n 2	

REGISTERS

0	1	2	3	4	5	6	7	8	9
	N	j	P	$(1 - P) = R_{L,x}$	$(1 - \gamma)$	$(1 - \gamma)$ calculated	γ	i	Logic

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title Reliability and Probability of Failure of Series and Parallel Systems

Contributor's Name Hewlett-Packard

Address 1000 N.E. Circle Blvd.

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables Given the mission time t, number of parallel components n_i, failure rates λ_{ij} and reliability block diagram of a parallel, series or combination parallel/series system, the program calculates the following values:

Probability of Failure $Q_s(t) = 1 - R_s(t)$

Reliability $R_s(t) = \prod_{i=1}^{k} R_i(t)$

where k = number of parallel groupings in series

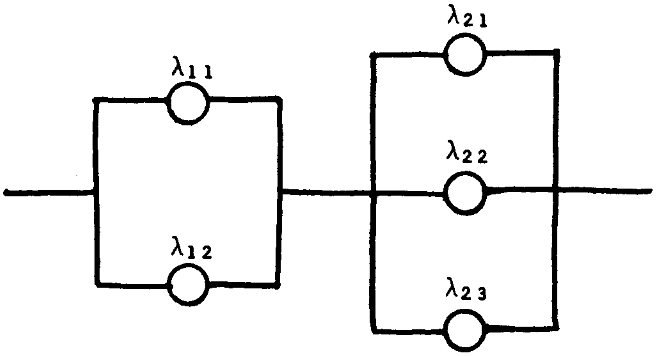
$$R_i = R_{i(j-1)} + (1 - R_{i(j-1)})R_{ij} \qquad 1 \geq j \geq n_i$$

$$R_{ij} = \exp(-\lambda_{ij}t)$$

Operating Limits and Warnings n is a positive integer and $\lambda \geq 0$.

Program Description II

Sketch(es)



Sample Problem(s)

Find the system reliability and probability of failure of the system represented on the line above, given the following failure rates and mission time:

$\lambda_{11} = 2 \times 10^{-4}$ failures/hour
$\lambda_{12} = 1.5 \times 10^{-2}$ "
$\lambda_{21} = 3.4 \times 10^{-3}$ "
$\lambda_{22} = 1.2 \times 10^{-2}$ "
$\lambda_{23} = 2.5 \times 10^{-2}$ "
$t = 10$ hours

Solution(s)

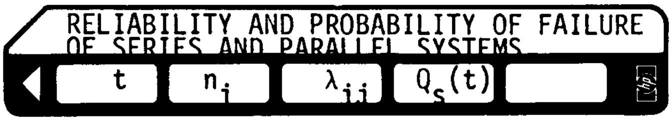
DSP 8
f A 10 A 2 B .0002 C .015 C
3 B .0034 C .025 C .012 C → .99888578 ($R_s(t)$)
D → .00111422 ($Q_s(t)$)

Reference(s)

Bazovsky, Igor, Reliability Theory and Practice, pgs. 17, 89, 98
Prentice Hall, 1961

This program is a translation of the HP-65 Users' Library program #03869A submitted by James E. Wells.

User Instructions



STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter program			
2	Initialize		f A	1.00
3	Enter mission time	t	A	t
4	Enter number of	n_i	B	n_i
	parallel components			
5	Perform step 5 for	λ_{ij}	C	j
	i = 1, 2,..., n-1			
6	Compute $R_s(t)$	λ_{in}	C	$R_s(t)$
7	Compute $Q_s(t)$		D	$Q_s(t)$
	(optional)			
	(for new case, go			
	to step 2)			

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLa	21 16 11	Initialize
002	P⇄S	16-51	
003	STO4	35 04	
004	STO5	35 05	
005	STO8	35 08	
006	1	01	
007	STO6	35 06	
008	RTN	24	
009	*LBLA	21 11	
010	STO5	35 05	Store 1 in R_6
011	RTN	24	Display 1 in R_6
012	*LBL1	21 01	Enter t
013	0	00	Initialize
014	STO1	35 01	Store 0 in R_1, R_3
015	STO3	35 03	
016	RCL6	36 06	
017	RTN	24	
018	*LBL2	21 02	
019	RTN	24	
020	*LBLB	21 12	
021	STO8	35 08	
022	RTN	24	
023	*LBL3	21 03	
024	RCL1	36 01	
025	RTN	24	
026	*LBLC	21 13	Display counter
027	ENT↑	-21	Calculate R_i
028	RCL5	36 05	
029	×	-35	
030	CHS	-22	
031	eˣ	33	
032	STO4	35 04	
033	RCL3	36 03	
034	CHS	-22	
035	ENT↑	-21	
036	1	01	
037	+	-55	
038	RCL4	36 04	$(1 - R_{i(j-1)})\ R_{ij}$
039	×	-35	
040	RCL3	36 03	
041	+	-55	
042	STO3	35 03	
043	RCL1	36 01	
044	1	01	Update counter
045	+	-55	
046	STO1	35 01	
047	RCL8	36 08	
048	X≠Y?	16-32	Test counter
049	GTO3	22 03	
050	RCL3	36 03	
051	ENT↑	-21	
052	RCL6	36 06	$R_s(t)$
053	×	-35	Store $R_s(t)$
054	STO6	35 06	
055	GTO1	22 01	
056	*LBLD	21 14	Calculate $Q_s(t)$
057	RCL6	36 06	
058	CHS	-22	
059	ENT↑	-21	
060	1	01	
061	+	-55	
062	GTO2	22 02	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	8

REGISTERS

0	1	2	3	4	5	6	7	8	9
	Counter		$R_{i(j-1)}$	R_{ij}	t	$R_s(t)$		n_i	

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title MIL-STD-883 CALCULATED LEAK RATE

Contributor's Name Hewlett-Packard

Address 1000 N.E. Circle Blvd.

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables

MIL-STD-883A Method 1014.1 Condition A_2 requires a calculated leak rate using the equation

$$R = L \frac{P_E}{P_0} \sqrt{\frac{M_a}{M}} \left\{ 1 - \exp\left[-L \frac{t_1}{VP_o} \sqrt{\frac{M_a}{M}} \right] \right\} \exp\left[-L \frac{t_2}{VP_o} \sqrt{\frac{M_a}{M}} \right]$$

To calculate L given the value for R. This equation must be solved iteratively for L. Solution is done using the Newton procedure for refining the trial values for L.

The user is referred to MIL-STD-883 for the meaning and complete description of variables and test techniques.

R = Measured leak rate

L = Calculated leak rate cc/sec

P_E = Bomb pressure (usually 5 atm)

t_1 = Pressurization time sec.

P_o = Atmospheric pressure (1 atm)

t_2 = Time from end of pressure to measurement sec.

$\frac{M_a}{M}$ = Ratio of molecular wts of air to tracer gas (assumed He)

Operating Limits and Warnings

Mathematically there is no limit, but calculation time is less for 1% than for .01%. 1% is adequate for most experimental setups.

Program Description II

Sketch(es)

Sample Problem(s)

For the inputs

$R = 7.2 \times 10^{-8}$

$t_1 = 3600$ sec

$t_2 = 300$ sec

$v = 1.1684$ cc

ERROR = .01

The program should return the value 8.058 -07. Keying RCL 3 will tell you that it took 6 iterations to obtain the answer.

Solution(s) Keystrokes: Outputs:

7.2 [EEX][CHS][8][STO][8], 3600 [STO][1], 300 [STO][2],
1.1684 [STO][3], 2.678 [STO][4], .01 [STO][5]

Keystrokes	Outputs
[SCI][DSP][3][A]	→ 8.058 -07
[RCL][3]	→ 6.000 00

Reference(s)

MIL-STD-883A "Military Standard Test Methods and Procedures for Microelectronics"

Method 1014.1 Seal

This program is a translation of the HP-65 Users' Library Program #04109A submitted by Richard T. Lamoureux.

User Instructions

MIL-STD-883 LEAK RATE				
GO				

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	ENTER PROGRAM			
2	INPUT DATA,			
	MEASURED RATE SCC/SEC	R	STO 8	R
	PRESSURIZATION TIME SEC	t_1	STO 1	t_1
	MEASUREMENT TIME SEC	t_2	STO 2	t_2
	PACKAGE VOLUME CC	v	STO 3	v
	RATIO MOL WT AIR TO He	a	STO 4	2.678
	ALLOWED ERROR	10^{-2}	STO 5	
3	SET DISPLAY		DSP 3	
4	START PROGRAM		A	L
	L IS CALCULATED LEAK RATE			
5	NUMBER OF ITERATIONS		RCL 3	n
	REQUIRED			
6	FOR NEXT CASE ENTER			
	MEASURED RATE	R	STO 8	R
	PRESSURIZATION TIME	t_1	STO 1	t_1
	MEASUREMENT TIME	t_2	STO 2	t_2
	PACKAGE VOLUME	v	STO 3	v
7	START PROGRAM		A	L

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	Start Calculation
002	RCL8	36 08	
003	CHS	-22	
004	STO7	35 07	
005	RCL4	36 04	
006	RCL3	36 03	
007	÷	-24	
008	ST×1	35-35 01	
009	ST×2	35-35 02	
010	0	00	
011	STO3	35 03	
012	*LBLB	21 12	
013	RCL7	36 07	Begin loop
014	RCL2	36 02	calculate R^-
015	×	-35	
016	e^x	33	
017	RCL7	36 07	
018	RCL1	36 01	
019	×	-35	
020	e^x	33	
021	1	01	
022	-	-45	
023	×	-35	
024	RCL4	36 04	
025	×	-35	
026	5	05	
027	×	-35	
028	RCL7	36 07	
029	×	-35	R^1
030	RCL8	36 08	begin test
031	-	-45	
032	STO6	35 06	
033	RCL8	36 08	
034	÷	-24	
035	ABS	16 31	
036	RCL5	36 05	
037	X>Y?	16-34	End test
038	GTOC	22 13	
039	RCL7	36 07	Begin calculation
040	RCL6	36 06	new L
041	RCL2	36 02	
042	4	04	
043	0	00	
044	×	-35	
045	RCL7	36 07	
046	×	-35	
047	2	02	
048	7	07	
049	-	-45	
050	RCL1	36 01	
051	×	-35	
052	RCL7	36 07	
053	×	-35	
054	÷	-24	
055	+	-55	
056	CHS	-22	
057	STO7	35 07	
058	1	01	
059	ST+3	35-55 03	
060	GTOB	22 12	L_{i+1}
061	RTN	24	
062	*LBLC	21 13	
063	RCL7	36 07	Display final L
064	CHS	-22	
065	R/S	51	
066	RTN	24	

SET STATUS

FLAGS	ON	OFF
0	☐	☒
1	☐	☒
2	☐	☒
3	☐	☒

TRIG	
DEG	☒
GRAD	☐
RAD	☐

DISP	
FIX	☒
SCI	☐
ENG	☐
n	3

REGISTERS

0	1	2	3	4	5	6	7	8	9
	t_b	t_c2	v_n	2.6785	10^{-2}	R^1-R	L	R	

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title MLE: $\hat{\theta}$ FROM HAZARD RATE

Contributor's Name Hewlett-Packard Company

Address 1000 N.E. Circle Boulevard

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables Given the test failure data of the sample, the program computes differential failure times (Δt_i); mean time to failure (MTTF); failure rate $Z(t_i)$; parameter λ (constant hazard rate) and $\hat{\theta}$ from this hazard rate.

Following formulas and variables are used:

1) $\Delta t_i = t_i - t_{i-1}$; where $i = 0,1,2,3,\ldots n$ failures

2) $MTTF = \hat{\theta} = \Sigma t_i / N_o$; where t_i = time to failures, N_o = total # of failures

3) $Z(t_i) = \dfrac{n(t_i) - n(t_i + \Delta t_i)}{\Delta t_i} \cdot \dfrac{1}{N_s(t_i)}$; where $[n(t_i) - n(t_i + \Delta t_i)]$ is # of failures in that time difference. $N_s(t_i)$ = # survived at t_i.

4) $\lambda = \dfrac{\Sigma Z(t_i)}{N_o} = \bar{Z}(t_i)$; λ = parameter (hazard rate) i.e. mean of total $Z(t_i)$'s.

5) $\hat{\theta}_{Z(t)} = \dfrac{1}{\lambda}$; [MLE from hazard rate]

hazard rate

Operating Limits and Warnings

Program Description II

Sketch(es)

P L E A S E S E E A T T A C H E D G R A P H

Sample Problem(s) Ten tires were put on testing machines with a known load and rpm: results were as follows.

FAILURE #	OPERATING TIME
1	6
2	22
3	30
4	45
5	62
6	88
7	114
8	140
9	190
10	251

Find the following:

1) Δt_i : differential time failures
2) MTTF: mean time to failure
3) $Z(t)$; failure rate parameter
4) λ : constant hazard rate
5) MLE: $\hat{\theta}$ from hazard rate

Solution(s)

Failure #	Operating Time	Δt_i	$Z(t_i)$
1	6	6	0.0167
2	22	16	0.0069
3	30	8	0.0156
4	45	15	0.0095
5	62	17	0.0098
6	88	26	0.0077
7	114	26	0.0096
8	140	26	0.0128
9	190	50	0.0100
10	251	61	0.0164
	$\Sigma t_i = 948$		$\Sigma Z(t_i) = 0.1151$

$$\lambda = \frac{\Sigma Z(t_i)}{N_o} = \frac{0.1151}{10}$$

$$\lambda = .01151$$

$$\hat{\theta} = \frac{1}{\lambda} = 86.8919$$

Reference(s) This program is a translation of the HP-65 Users' Library Program #05105A submitted by Ashok H. Doshi.

COMPLETE KEYSTROKES FOR THE EXAMPLE

	[f] [REG]	0.00	(Clear registers)
251	[A]	251.00	(t_{10})
190	[R/S]	61.00	(Δt_{10})
	[R/S]	190.00	[Recall last input]
140	[R/S]	50.00	(Δt_9)
	[R/S]	140.00	[Recall last input]
114	[R/S]	26.00	(Δt_8)
	[R/S]	114.00	[Recall last input]
88	[R/S]	26.00	(Δt_7)
	[R/S]	88.00	[Recall last input]
62	[R/S]	26.00	(Δt_6)
	[R/S]	62.00	[Recall last input]
45	[R/S]	17.00	(Δt_5)
	[R/S]	45.00	[Recall last input]
30	[R/S]	15.00	(Δt_4)
	[R/S]	30.00	[Recall last input]
22	[R/S]	8.00	(Δt_3)
	[R/S]	22.00	[Recall last input]
6	[R/S]	16.00	(Δt_2)
	[R/S]	6.00	[Recall last input]
0	[R/S]	6.00	(Δt_1)
	[R/S]	0.00	[Recall last input]
	[B]	94.80	($\hat{\theta}$)
6	[C]	0.0167	[$Z(t_1)$]
16	[R/S]	0.0069	[$Z(t_2)$]
8	[R/S]	0.0156	[$Z(t_3)$]
15	[R/S]	0.0095	[$Z(t_4)$]
17	[R/S]	0.0098	[$Z(t_5)$]
26	[R/S]	0.0077	[$Z(t_6)$]
26	[R/S]	0.0096	[$Z(t_7)$]
26	[R/S]	0.0128	[$Z(t_8)$]
50	[R/S]	0.0100	[$Z(t_9)$]
61	[R/S]	0.0164	[$Z(t_{10})$]

User Instructions

MLE: $\hat{\theta}$ FROM HAZARD RATE

Δt_i	MLE $\hat{\theta}$	$Z(t_i)$	λ	$\hat{\theta}_{Z(t)}$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Enter Program			
2	Initialize		[RTN]	
3	Clear Registers		[f] [REG]	0.00
4	Input last operating time	t_n	[A]	t_n
5	Input preceeding times	t_r	[R/S]	Δt_i
	repeat 5 - 6 for			
6	t_r = r = n-1, n-2,...3,2,1,0		[R/S]	t_r
7	Compute MTTF: $\hat{\theta}$		[B]	$\hat{\theta}$
8	Input Δt_1 (first time diff.)	Δt_1	[C]	$Z(t_1)$
9	Input next time diff.			
	Δt_i ; i = 2,3,4,...n-1,n	Δt_i	[R/S]	$Z(t_i)$
	Repeat 9 for i = 1,2,3,...n			
10	Compute parameter λ		[D]	λ
11	Compute MLE: $\hat{\theta}$ from the hazard rate		[E]	MLE: $\hat{\theta}_{Z(t)}$
12	For new case go to step 2			

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	Calculate the operating time differences
002	*LBL3	21 03	
003	ST+1	35-55 01	
004	R/S	51	
005	-	-45	
006	DSZI	16 25 46	
007	GTO4	22 04	
008	GTO3	22 03	
009	*LBL4	21 04	
010	R/S	51	
011	LSTX	16-63	
012	GTO3	22 03	
013	*LBLB	21 12	
014	RCL1	36 01	Calculate MTTF: $\hat{\theta}$
015	RCLI	36 46	
016	CHS	-22	
017	÷	-24	
018	RTN	24	
019	*LBLC	21 13	
020	1/X	52	Calculate $Z(t_i)$ (failure rate)
021	RCLI	36 46	
022	CHS	-22	
023	÷	-24	
024	ST+2	35-55 02	
025	RCL2	36 02	
026	DSP4	-63 04	
027	*LBL1	21 01	
028	R/S	51	
029	1/X	52	
030	RCLI	36 46	
031	1	01	
032	ST+5	35-55 05	
033	RCL5	36 05	
034	X⇄Y	-41	
035	R↓	-31	
036	+	-55	
037	÷	-24	
038	CHS	-22	
039	ST+2	35-55 02	
040	GTO1	22 01	
041	*LBLD	21 14	Calculate the parameter λ (constant hazard rate)
042	RCL2	36 02	
043	RCLI	36 46	
044	CHS	-22	
045	÷	-24	
046	DSP4	-63 04	
047	RTN	24	
048	*LBLE	21 15	Calculate MLE: $\hat{\theta}_{Z(t)}$
049	GSBD	23 14	
050	1/X	52	
051	DSP4	-63 04	
052	RTN	24	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	2

REGISTERS

0	1	2	3	4	5	6	7	8	9
	USED	USED			USED			USED	

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title MLE: $\hat{\theta}$ BY LEAST SQUARE METHOD

Contributor's Name Hewlett-Packard

Address 1000 N.E. Circle Boulevard

City Corvallis State Oregon Zip Code 97330

Program Description, Equations, Variables

The program uses least square technique to compute maximum likelihood estimator. By using the probability of survival $R(t_i)$

where:

$$R(t_i) = \frac{N_s}{N_o} \quad ;$$

N_s = numbers survived at time t_i.

N_o = total number failed

least square parameter

$$\lambda = -\frac{\sum_{i=1}^{n} t_i \ln R(t_i)}{\sum_{i=1}^{n} t_i^2} \quad ;$$

for detail see page 4 of 7

and

$$\hat{\theta} = \frac{1}{\lambda} \quad ;$$

maximum likelihood estimator

Operating Limits and Warnings

DEVELOPING θ BY GENERATING THE PARAMETER λ USING RELIABILITY FOR LEAST SQUARE METHOD

Using Least Square Estimate

To Find value of parameter λ

$$R(t_i) = e^{-\lambda t_i}$$

$$\ln R(t_i) = -\lambda t_i$$

$$s(\lambda) = \Sigma\,[\ln R(t_i) - (-\lambda t_i)]^2$$

Now taking derivative w.r.t. λ on both sides and equating to zero for maximum we get:

$$\frac{d\,s(\lambda)}{d\,\lambda} = \Sigma 2[\ln R(t_i) + \lambda t_i\,]\,(t_i) = 0$$

$$\Sigma 2[\ln R(t_i) + \lambda t_i](t_i) = 0$$

$$\Sigma 2[t_i \ln R(t_i) + \lambda t_i^2] = 0$$

$$2\Sigma [t_i \ln R(t_i) + \lambda t_i^2] = 0$$

$$\sum_{i=1}^{n} t_i \ln R(t_i) + \lambda \sum_{i=1}^{n} t_i^2 = 0$$

$$\lambda = \frac{-\sum_{i=1}^{n} t_i \ln R(t_i)}{\sum^{n} t_i^2}$$

Program Description II

Sketch(es)

Sample Problem(s) Ten tires were put on testing machines with a known load and rpm. The test results of failures were as follows:

FAILURE #	OPERATING TIME
1	6
2	22
3	30
4	45
5	62
6	88
7	114
8	140
9	190
10	251

FIND THE FOLLOWING:

1) probability of survival $R(t_i)$
2) MLE: θ by using least square method

Solution(s) For solution please see pages attached next 4 of 7 and 5 of 7.

Reference(s) Authors Own Notes On "Quality Assurance and Reliability".

This program is a translation of the HP-65 Users' Library Program #05106A submitted by Ashok Doshi.

COMPLETE KEYSTROKES FOR THE EXAMPLE

	Press	Display	
	[f] [REG]	0.00	[Clear Registers]
6	[A]	36.00	[t_1^2]
22	[A]	484.00	[t_2^2]
30	[A]	900.00	[t_3^2]
45	[A]	2025.00	[t_4^2]
62	[A]	3844.00	[t_5^2]
88	[A]	7744.00	[t_6^2]
114	[A]	12996.00	[t_7^2]
140	[A]	19600.00	[t_8^2]
190	[A]	36100.00	[t_9^2]
251	[A]	63001.00	[t_{10}^2]
	[B]	0.9000	[$R(t_1)$]
	[B]	0.8000	[$R(t_2)$]
	[B]	0.7000	[$R(t_3)$]
	[B]	0.6000	[$R(t_4)$]
	[B]	0.5000	[$R(t_5)$]
	[B]	0.4000	[$R(t_6)$]
	[B]	0.3000	[$R(t_7)$]
	[B]	0.2000	[$R(t_8)$]
	[B]	0.1000	[$R(t_9)$]
	[B]	0.0000	[$R(t_{10})$]

PRESS		DISPLAY	
.9	[C]	-0.1054	[ln R(t_1)]
.8	[C]	-0.2231	[ln R(t_2)]
.7	[C]	-0.3567	[ln R(t_3)]
.6	[C]	-0.5108	[ln R(t_4)]
.5	[C]	-0.6931	[ln R(t_5)]
.4	[C]	-0.9163	[ln R(t_6)]
.3	[C]	-1.2040	[ln R(t_7)]
.2	[C]	-1.6094	[ln R(t_8)]
.1	[C]	-2.3026	[ln R(t_9)]
.0	→ (not possible)	--	← [ln R(t_{10})]
6	[D]	6.00	[t_1]
.1054	[CHS] [R/S]	- 0.6324	[t_1 · ln R(t_1)]
22	[D]	22.0000	[t_2]
.2231	[CHS] [R/S]	- 4.9082	[t_2 · ln R(t_2)]
30	[D]	30.0000	[t_3]
.3567	[CHS] [R/S]	- 10.7010	[t_3 · ln R(t_3)]
45	[D]	45.0000	[t_4]
.5108	[CHS] [R/S]	- 22.9860	[t_4 · ln R(t_4)]
62	[D]	62.0000	[t_5]
.6931	[CHS] [R/S]	- 42.9722	[t_5 · ln R(t_5)]
88	[D]	88.0000	[t_6]
.9163	[CHS] [R/S]	- 80.6344	[t_6 · ln R(t_6)]
114	[D]	114.0000	[t_7]
1.2040	[CHS] [R/S]	- 137.2560	[t_7 · ln R(t_7)]
140	[D]	140.0000	[t_8]
1.6094	[CHS] [R/S]	- 225.3160	[t_8 · ln R(t_8)]
190	[D]	190.0000	[t_9]
2.3026	[CHS] [R/S]	- 437.4940	[t_9 · ln R(t_9)]
[Delete]→251	[D]	251.0000	[t_{10}]
this one only	[R/S]	--	[t_{10} · ln R(t_{10})]
	[E]	152.3834	[$\hat{\theta}$]

BY LEAST SQUARE ESTIMATE METHOD USING R(t)

ie $$\lambda = - \frac{\sum_{i=1}^{10} t_i \ln R(t_i)}{\sum_{i=1}^{10} t_i^2}$$ (as formed previously)

	t_i	$R(t_i)$	$\ln R(t_i)$	$t_i \ln R(t_i)$	t_i^2
1	6	0.90	- 0.1054	- 0.6324	36
2	22	0.80	- 0.2231	- 4.9082	484
3	30	0.70	- 0.3567	- 10.7010	900
4	45	0.60	- 0.5108	- 22.9860	2025
5	62	0.50	- 0.6931	- 42.9722	3844
6	88	0.40	- 0.9163	- 80.6344	7744
7	114	0.30	- 1.2040	- 137.2560	12996
8	140	0.20	- 1.6094	- 225.3160	19600
9	190	0.10	- 2.3026	- 437.4940	36100
10	251	0.00	--	--	63001
				λ = - 962.90	146730

$$\therefore \quad \lambda = - \frac{-962.90}{146730} = 0.0066 \qquad \therefore \quad \hat{\theta} = \frac{1}{\lambda} = 152.3834$$

User Instructions

1 MLE: $\hat{\theta}$ BY LEAST SQUARE METHOD 2

t_i^2 | $R(t_i)$ | $L_N R(t_i)$ | $t_i L_N R(t_i)$ | $\hat{\theta}$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter Program				
2	Initialize		RTN		
3	Clear registers		f	REG	0.00
4	Input t_i (operating time)	t_i	A		t_i^2
	repeat 4 for i = 1, 2, 3,... n				
5	Compute $R(t_i)$ Probability of survival		B		$R(t_i)$
	repeat 5 for i = 1, 2, 3,...n				
6	Input probability of survival $R(t_i)$	$R(t_i)$	C		L_N $R(t_i)$
	repeat 6 for i = 1, 2, 3,... n				
7	Input operating time t_i	t_i	D		t_i
8	Input L_N $R(t_i)$	L_N $R(t_i)$	R/S		t_i $L_N R(t_i)$
	repeat 7-8 for i = 1, 2, 3,... n				
9	Compute $\hat{\theta}$		E		$\hat{\theta}$
10	For new case go to step 2				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	Compute t^2
002	X²	53	
003	ST+1	35-55 01	
004	1	01	
005	ST+2	35-55 02	
006	X⇄Y	-41	
007	RTN	24	
008	*LBLB	21 12	Compute $R(t_i)$ probability of survival
009	RCL2	36 02	
010	ENT↑	-21	
011	ENT↑	-21	
012	ENT↑	-21	
013	1	01	
014	ST+3	35-55 03	
015	RCL3	36 03	
016	X⇄Y	-41	
017	R↓	-31	
018	-	-45	
019	X⇄Y	-41	
020	÷	-24	
021	DSP4	-63 04	
022	RTN	24	
023	*LBLC	21 13	Input $R(t_i)$
024	LN	32	Compute $L_N\ R(t_i)$
025	RTN	24	
026	*LBLD	21 14	Input t_i
027	ENT↑	-21	
028	R/S	51	Input $L_N\ R(t_i)$
029	×	-35	
030	ST+4	35-55 04	Compute $[t_iR(t_i)]$
031	RTN	24	
032	*LBLE	21 15	
033	RCL4	36 04	Compute θ
034	RCL1	36 01	
035	÷	-24	
036	CHS	-22	
037	1/X	52	
038	RTN	24	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	2

REGISTERS

0	1	2	3	4	5	6	7	8	9
	Used Σt_i^2	Used # of fail.	Used	Used $\Sigma[t_iL_NR(t_i)]$					
S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title SYSTEMS RELIABILTY - SERIES AND PARALLEL WITH SAME FAILURE RATE λ

Contributor's Name Hewlett-Packard Company

Address 1000 N.E. Circle Boulevard

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables Program calculates total systems reliability when units (composed of differential components) are placed in series or parallel, by using the concept of unreliability to calculate systems reliability in parallel, avoiding very lengthy and tedious calculations. Saves considerable amount of time. Equations used are as follows:

j_i is number of components of corresponding λ_i

λ_i is failure rate/hr of differential components (say r types) (where i = 1, 2, 3, ... r)

$\sum_{i=1}^{r} j_i \lambda_i$; total failure rate/hr of a unit

Unit $R_s(t) = e^{-\sum_1^n \lambda_i j_i \cdot t}$; Unit reliability for t hours.

Unit $Q_s(t) = 1 - R_s(t)$; Unit unreliability for t hours.

$$\text{Series } R_{sys} = \prod_{m=1}^{n} R_m = \prod_{m=1}^{n} e^{-[\sum_1^r \lambda_i j_i \cdot t]_m} = [e^{-\sum_1^r \lambda_i j_i \cdot t}]^n$$

$$\text{Series } Q_{sys} = 1 - R_{sys}$$

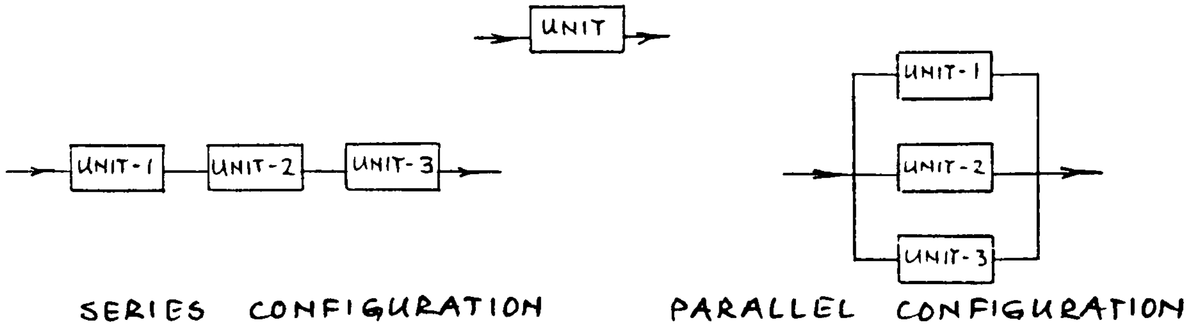
$$\text{Parallel } R'_{sys} = 1 - \prod_{m=1}^{n} Q'_m = [1 - [1 - \prod_{m=1}^{n} [R_s(t)]_m]$$

Operating Limits and Warnings

All units placed in series or parallel <u>must</u> have same λ failure rate per hour.

Program Description II

Sketch(es)



Sample Problem(s) The given electrical unit has following components with corresponding failure rates:

chronological order i	# of components j	ε failure rate/hr/comp. λ	$\lambda_i j_i$
1	2-diodes	2.0×10^{-6}/hr	4.0×10^{-6}/hr
2	3-transistors	10.0×10^{-6}/hr	30.0×10^{-6}/hr
3	1-capacitor	1.0×10^{-6}/hr	1.0×10^{-6}/hr
4	2-resistors	2.0×10^{-6}/hr	4.0×10^{-6}/hr

Find for t = 1000 hours; following:

1) Reliability, unreliability of a unit: $R_s(t)$ & $Q_s(t)$
2) Series reliability R_{sys}; unreliability for 3 units (n=3)
3) Parallel unreliability Q_{sys}; reliability for 3 units (n=3)
4) Total failure rate/hour of an unit: $(\sum_{1}^{r} \lambda_i j_i)$

Solution(s) $\sum_{i=1}^{r} \lambda_i j_i$ = 3.9000000 -05

Unit: $R_s(1000)$ = 0.961751 ; $Q_s(1000)$ = 0.038249

Series System: for n=3 $R_{sys}(1000)$ = 0.889585 ; $Q_s(1000)$ = 0.110415

Parallel System: for n=3 $Q'_s(1000)$ = 0.000056 ; $R'_s(1000)$ = 0.999944

Reference(s) Authors Own Notes on "Quality Assurance And Reliability". This program is a translation of the HP-65 Users' Library Program #05108A submitted by Ashok Doshi.

COMPLETE KEYSTROKES FOR THE EXAMPLE

[A]	0.00		
2 [EEX]	2.	00	
6	2.	06	
[CHS]	2.	-06	[λ_i]
[↑]			
[2]			[# of components]
[X]	0.00		
[B]	4.000000000	-06	[$\Sigma\ \lambda_i j_i$]
10 [EEX]	10.	00	
6	10.	06	
[CHS]	10.	-06	
[↑]	10.000000000	-06	
3	3.		
[X]			
[B]	3.400000000	-05	
[EEX]	1.	00	
6	1.	06	
[CHS] [↑]	1.000000000	-06	
1	1.		
[X]	1.000000000	-06	
[B]	3.500000000	-05	
2 [EEX]	2.	00	
6	2.	06	
[CHS]	2.	-06	
[↑]	2.000000000	-06	
2	2.		
[X]			
[B]	3.900000000	-05	
1000 [C]	0.961751		[$R_s(1000)$]
[R/S]	0.038249		[$Q_s(1000)$]
3 [D]	0.889585		[$R_{sys}^{(1000)}$ when we input n=3 units in series]
[R/S]	0.110415		[$Q_{sys}^{(1000)}$ of 3 units in series]
3 [E]	0.000056		[$Q'_s(1000)$ of 3 units in parallel]
[R/S]	0.999944		[$R'_s(1000)$ of 3 units in parallel]

User Instructions

1 SYSTEM RELIABILITY - SERIES OR PARALLEL SYSTEM WITH SAME λ 2

Init	$\Sigma\lambda_i j_i$	Unit $R_s(t)$ $Q_s(t)$	Series R_{sys} Q_{sys}	Parallel Q'_{sy} R'_{sy}

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Initialize, clear registers		A		0.00
3	Input λ_i for each component	λ_i	↑		
4	Input j_i # of components	j_i	X		$\lambda_i j_i$
5	Sum & Recall $\Sigma\lambda_i j_i$		B		$\Sigma\lambda_i j_i$
	repeat 3-5 for i = 1, 2, 3, ...r				
6	Input time 't' for reliability	t	C		Unit $R_s(t)$
7	Calculate unreliability		R/S		Unit $Q_s(t)$
8	Input no. of units in series to calculate	n	D		Series R_{sys}
	systems reliability in series				
9	Calculate unreliability for new 'n'		R/S		Series Q_{sys}
	Go to step 8				
10	Input no. of units in parallel for	n	E		Parallel
	systems unreliability				Q' sys
11	Calculate reliability of parallel system		R/S		Parallel
					R' sys
	For new 'n' go to step 8 or 10 as requires				
	For a new case go to step 2				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	Initialize, clear
002	CLRG	16-53	registers
003	RTN	24	
004	*LBLB	21 12	
005	ST+1	35-55 01	Calculate $\Sigma\lambda_{iji}$
006	RCL1	36 01	(total unit
007	SCI	-12	failure rate)
008	DSP9	-63 09	
009	RTN	24	
010	*LBLC	21 13	
011	RCL1	36 01	Calculate unit's
012	x	-35	reliability and
013	CHS	-22	unreliability
014	e^x	33	
015	FIX	-11	
016	DSP6	-63 06	
017	STO2	35 02	
018	R/S	51	
019	CHS	-22	
020	1	01	
021	+	-55	
022	STO3	35 03	
023	RTN	24	
024	*LBLD	21 14	
025	RCL2	36 02	Calculate R_{sys}
026	X⇄Y	-41	reliability in
027	Y^x	31	series for 'n'
028	FIX	-11	such units
029	DSP6	-63 06	
030	R/S	51	Yield unreliability
031	CHS	-22	in series Q_{sys}
032	1	01	
033	+	-55	
034	RTN	24	
035	*LBLE	21 15	
036	RCL3	36 03	Calculate Q_{sys}
037	X⇄Y	-41	unreliability to
038	Y^x	31	find paralled
039	FIX	-11	systems reliab.
040	DSP6	-63 06	for 'n' units
041	R/S	51	Yields R_{sys}
042	CHS	-22	reliability of
043	1	01	system in parallel
044	+	-55	
045	RTN	24	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	2

REGISTERS

0	1	2	3	4	5	6	7	8	9
	USED	USED	USED						

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

Program Description I

Program Title SYSTEMS RELIABILITY - SERIES AND PARALLEL WITH DIFFERENT FAILURE RATE λ

Contributor's Name Hewlett-Packard Company

Address 1000 N.E. Circle Boulevard

City Corvallis **State** Oregon **Zip Code** 97330

Program Description, Equations, Variables

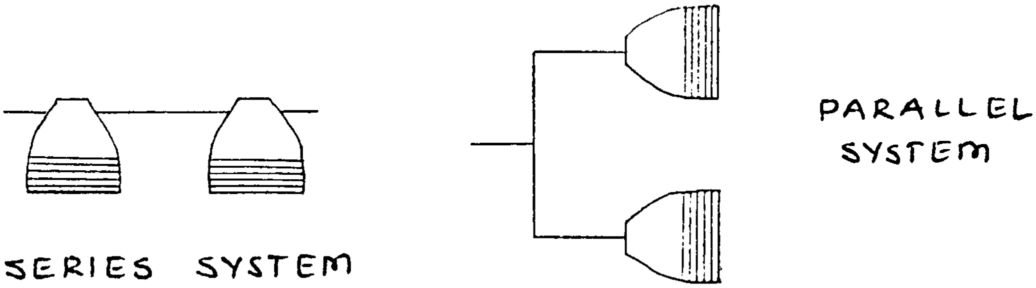
For series system, program uses $R_{ss} = \prod_{i=1}^{n} R_i$ (where R_i = reliability of each component or unit) and for parallel system it uses unreliability concept to find reliability of the system. $R_{sp} = 1 - Q_{sp}$ (where $Q_{sp} = \prod_{i=1}^{n} (1-e^{-\lambda_i t})$. λ is failure rate/hour.

The program is very useful to check out any dependent failures, repairs, sand by operation and redundency of the system.

Operating Limits and Warnings

Program Description II

Sketch(es)



Sample Problem(s) Two retro rockets of differnet capacities with failure rates 6×10^{-6} F/Hr and 23×10^{-6} F/Hr respectively of a command module of a spacecraft are to be mounted for maximum possible systems reliability for re-entry. Find out systems reliability for 1000 hours. If they are mounted in series or parallel. (Please refer to sketch above).

ie GIVEN: $t = 1000$

$\lambda_1 = 6 \times 10^{-6}$ Failures/hour

$\lambda_2 = 23 \times 10^{-6}$ Failures/hour

Solution(s)

$$R_{ss}(1000) = \prod_{i=1}^{n} R_i = e^{-\lambda_1 t} \cdot e^{-\lambda_2 t} = e^{-6x10^{-6}x1000} \cdot e^{-23x10^{-6}x1000} = 0.971416$$

$$Q_{ss}(1000) = 0.028584$$

$$R_{sp}(1000) = 1 - Q_{sp} = [1 - (1-R_1)(1-R_2)] = 0.999864$$

$$Q_{sp}(1000) = (1-R_1)(1-R_2) = (1-e^{-\lambda_1 t})(1-e^{-\lambda_2 t}) = 0.000136$$

Reference(s)

1) "Probabilistic Reliability: An Engineering Approach" Martin Shooman, McGraw-Hill.

2) HP-65 Owners Handbook

This program is a translation of the HP-65 Users' Library Program #05109A submitted by Ashok Doshi.

COMPLETE KEYSTROKES FOR THE EXAMPLE

	[f] [REG]	0.00		[Clear Registers]
	[DSP] [6]			
1000	.	1000		[Input Time t]
	[A]	1.00		
6	[EEX]	6.	00	
6		6.	06	
	[CHS]	6.	-06	[Input λ_i]
	[B]	0.994018		[Inter-mediate R_{ss}]
23	[EEX]	23.	00	
6		23.	06	
	[CHS]	23.	-06	[Input λ_i]
	[B]	0.971416		[R_{ss} - Reliability in series]
	[C]	0.028584		[Q_{ss} - Unreliability in series]
6	[EEX]	6.	00	
6		6.	06	
	[CHS]	6.	-06	[Input λ_i]
	[D]	0.005982		[Q_{sp}- Intermediate Unreliability in parallel]
23	[EEX]	23	00	
6		23	06	
	[CHS]	23	-06	[Input λ_i]
	[D]	0.000136		[Q_{sp}-Unreliability in parallel]
	[E]	0.999864		[R_{sp}-Reliability in parallel]

User Instructions

1 SYSTEMS RELIABILITY IN SERIES AND PARALLEL DIFFERENT λ 2

t	R_{ss}	Q_{ss}	Q_{sp}	R_{sp}

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
1	Enter program				
2	Clear registers		f	REG	0.00
3	Input time t	t	A		1.00
4	Input λ_i for each component	λ_i	B		R_{ss}
	repeat 4 for i = 1, 2, 3, ...n				series
5	Calculate unreliability (Series)		C		Q_{ss}
					series
6	Input λ_i for each of the component to	λ_i	D		Q_{sp}
	calculate unreliability of parallel system				parallel
	repeat 6 for i = 1, 2, 3, ...n				
7	Calculate reliability of parallel system		E		R_{sp}
					parallel
	For a new case go to step 2				

97 Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	*LBLA	21 11	Store time and
002	ST+3	35-55 03	activate storage
003	1	01	register 1 and 4
004	ST+1	35-55 01	
005	ST+4	35-55 04	
006	RTN	24	
007	*LBLB	21 12	Calculate
008	RCL3	36 03	reliability R_{ss}
009	×	-35	of the series
010	CHS	-22	system
011	e^x	33	
012	ST×1	35-35 01	
013	RCL1	36 01	Yields R_{ss}-series
014	RTN	24	
015	*LBLC	21 13	
016	RCL1	36 01	Calculate unreliab-
017	CHS	-22	ility of the
018	1	01	series system
019	+	-55	yields Q_{ss} of
020	RTN	24	series system
021	*LBLD	21 14	Calculate Q_{sp} of
022	RCL3	36 03	parallel system
023	×	-35	for the use of
024	CHS	-22	unreliability
025	e^x	33	concept
026	CHS	-22	
027	1	01	
028	+	-55	
029	ST×4	35-35 04	yields Q_{sp} for
030	RCL4	36 04	parallel system
031	RTN	24	
032	*LBLE	21 15	
033	RCL4	36 04	Calculate R_{sp}
034	CHS	-22	reliability of
035	1	01	parallel system
036	+	-55	Yields R_{sp} for
037	RTN	24	parallel system

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☒	DEG	☒	FIX	☒
1	☐	☒	GRAD	☐	SCI	☐
2	☐	☒	RAD	☐	ENG	☐
3	☐	☒			n	6

REGISTERS

0	1	2	3	4	5	6	7	8	9
	USED		USED	USED					

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9

A	B	C	D	E	I

NOTES

NOTES

NOTES

Hewlett-Packard Software

In terms of power and flexibility, the problem-solving potential of the Hewlett-Packard line of fully programmable calculators is nearly limitless. And in order to see the practical side of this potential, we have several different types of software to help save you time and programming effort. Every one of our software solutions has been carefully selected to effectively increase your problem-solving potential. Chances are, we already have the solutions you're looking for.

Application Pacs

To increase the versatility of your fully programmable Hewlett-Packard calculator, HP has an extensive library of "Application Pacs". These programs transform your HP-67 and HP-97 into specialized calculators in seconds. Each program in a pac is fully documented with commented program listing, allowing the adoption of programming techniques useful to each application area. The pacs contain 20 or more programs in the form of prerecorded cards, a detailed manual, and a program card holder. Every Application Pac has been designed to extend the capabilities of our fully programmable models to increase your problem-solving potential.

You can choose from:

Statistics
Mathematics
Electrical Engineering
Business Decisions
Clinical Lab and Nuclear Medicine
Mechanical Engineering
Surveying
Civil Engineering
Navigation
Games

Users' Library

The main objective of our Users' Library is dedicated to making selected program solutions contributed by our HP-67 and HP-97 users available to you. By subscribing to our Users' Library, you'll have at your fingertips, literally hundreds of different programs. No longer will you have to: research the application; program the solution; debug the program; or complete the documentation. Simply key your program to obtain your solution. In addition, programs from the library may be used as a source of programming techniques in your application area.

A one-year subscription to the Library costs $9.00. You receive: a catalog of contributed programs; catalog updates; and coupons for three programs of your choice (a $9.00 value).

Users' Library Solutions Books

Hewlett-Packard recently added a unique problem-solving contribution to its existing software line. The new series of software solutions are a collection of programs provided by our programmable calculator users. Hewlett-Packard has currently accepted over 6,000 programs for our Users' Libraries. The best of these programs have been compiled into 40 Library Solutions Books covering 39 application areas (including two game books).

Each of the Books, containing up to 15 programs without cards, is priced at $10.00, a savings of up to $35.00 over single copy cost.

The Users' Library Solutions Books will compliment our other applications of software and provide you with a valuable new tool for program solutions.

Options/Technical Stock Analysis
Portfolio Management/Bonds & Notes
Real Estate Investment
Taxes
Home Construction Estimating
Marketing/Sales
Home Management
Small Business
Antennas
Butterworth and Chebyshev Filters
Thermal and Transport Sciences
EE (Lab)
Industrial Engineering
Aeronautical Engineering
Control Systems
Beams and Columns
High-Level Math
Test Statistics
Geometry
Reliability/QA
Medical Practitioner
Anesthesia
Cardiac
Pulmonary
Chemistry
Optics
Physics
Earth Sciences
Energy Conservation
Space Science
Biology
Games
Games of Chance
Aircraft Operation
Avigation
Calendars
Photo Dark Room
COGO-Surveying
Astrology
Forestry

RELIABILITY/QUALITY ASSURANCE

Calculations related to reliability/quality assurance are included in this book, e.g., intra-class correlation, specific compliance, parameter estimation, lower limit and bounds of reliability, failure of serves, leak rate, maximum likelihood estimator, system reliability, distribution function, comparison of hazard models, etc.

RELIABILITY: INTRA-CLASS CORRELATION

SPECIFICATION COMPLIANCE FROM LIMITS AND REGRESSION ANALYSIS

PARAMETER ESTIMATION (EXPONENTIAL DISTRIBUTION)

LOWER LIMIT OR RELIABILITY — BINOMIAL DISTRIBUTION

RELIABILITY AND PROBABILITY OF FAILURE OF SERIES AND PARALLEL SYSTEMS

MIL - STD - 883 CALCULATED LEAK RATE

MLE: $\hat{\theta}$ FROM HAZARD RATE

MLE: $\hat{\theta}$ BY LEAST SQUARE METHOD

SYSTEMS RELIABILITY-SERIES AND PARALLEL WITH SAME FAILURE RATE λ

SYSTEMS RELIABILITY-SERIES AND PARALLEL WITH DIFFERENT FAILURE RATE λ

HEWLETT PACKARD

1000 N.E. Circle Blvd., Corvallis, OR 97330

Reorder No. 00097-14030 Printed in U.S.A. 00097-90205

Revision C 10-78