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A GENERALIZED METHOD FOR COMPUTING THE PROBABILITY OF KILLING X--ETC(U)
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MEMORANDUM REPORT ARBRL-MR-02890

A GENERALIZED METHOD FOR COMPUTING THE PROBABILITY OF KILLING X TARGETS OUT OF N TARGETS

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January 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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A general equation for computing the probability of X successes out of N trials with unequal or equal individual probabilities is presented. Computer codes for performing the calculations are also presented in both FORTRAN and BASIC languages.

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I. INTRODUCTION

In the process of conducting live firings of missiles equipped with warheads containing numerous bomblets, a problem arose pertaining to the evaluation of the effectiveness of the bomblets against various targets. The targets included personnel simulators and surface-to-air missiles.

Briefly, it was necessary to determine the probability of kill (P_k) of a group of target items when some or all of them were damaged to unequal levels of kill. In essence, it was required to compute the probability of achieving exactly and/or at least X kills (successes) out of a sample of N trials when the individual P_k values were not necessarily equal.

II. PROCEDURE

Standard textbook methods[1] use the following equation for computing the probability of X successes out of N trials when the probability of success p, is constant from trial to trial and the N trials are independent:

$$P(X;N,p) = \binom{N}{X} p^X (1-p)^{N-X}$$

$$= \binom{N}{X} p^X q^{N-X} \qquad (1)$$

where X = 0,1,2 . . . N,

$$\binom{N}{X} = \frac{N!}{X!\,(N-X)!}$$

and q = 1 - p.

However, in the case under consideration here, the values for p are not necessarily equal and Eq. (1) cannot be used to compute the probability of exactly X successes out of N trials, $P(X;N,p_i)$ which, for the sake of simplicity, we will express as $P\binom{N}{X}$ throughout the

1 *Freund, J.E., "Mathematical Statistics", Englewood Cliffs, NJ: Prentice-Hall, 1962*

remainder of this report. Instead, consider the following expression which can be used to determine $P\binom{N}{X}$ for unequal (or equal, for the trivial case) probability values, p_i:

$$P\binom{N}{X} = \sum_{j=1}^{2^N} \beta_j \prod_{i=1}^{N} p_i^{\delta_{i,j}} \; q_i^{1-\delta_{i,j}} \qquad (2)$$

where the $\delta_{i,j}$'s are chosen to equal 0 or 1 to satisfy Eq. (3) for each j,

$$j-1 = \sum_{i=1}^{N} \delta_{i,j} \, 2^{i-1} \qquad (3)$$

and β_j is defined as

$$\beta_j = 1 \quad \text{iff} \quad \sum_{i=1}^{N} \delta_{i,j} = X \qquad (4)$$

$$= 0, \text{ otherwise.}$$

As a simple example, consider the case of determining the probability of at least 1 success out of 3 events and exactly 1, exactly 2, and exactly 3 successes out of 3 events. Using Eq. (3) and Eq. (4) where $j = 1$ to 2^3 and $N = 3$, the $\delta_{i,j}$'s and β_j's are determined as follows:

For $j = 1$,

$$j-1 = \sum_{i=1}^{3} \delta_{i,j} \; 2^{i-1}$$

$$0 = \delta_{1,1} 2^0 + \delta_{2,1} 2^1 + \delta_{3,1} 2^2$$

In order for the above equation to be valid, $\delta_{1,1}$ must equal 0,

$\delta_{2,1}$ must equal 0, and $\delta_{3,1}$ must equal 0, and therefore the $\sum_{i=1}^{3} \delta_{i,j} = 0$. Consequently using Eq. (4), for X = 1, β_1 must equal 0, for X = 2, β_1 must equal 0 and for X = 3, β_1 must equal 0.

For j = 2,

$$j-1 = \sum_{i=1}^{3} \delta_{i,j} \, 2^{i-1}$$

$$1 = \delta_{1,2} \, 2^0 + \delta_{2,2} \, 2^1 + \delta_{3,2} \, 2^2$$

Similarly, for the above equation to be valid, $\delta_{1,2}$ must equal 1, $\delta_{2,2}$ must equal 0 and $\delta_{3,2}$ must equal 0, and therefore $\sum_{i=1}^{3} \delta_{i,j} = 1$. Again, using Eq. (4) for X = 1, β_2 must equal 1, for X = 2, β_2 must equal 0 and for X = 3, β_2 must equal 0.

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For j = 8,

$$j-1 = \sum_{i=1}^{3} \delta_{i,j} \, 2^{i-1}$$

$$7 = \delta_{1,8} \, 2^0 + \delta_{2,8} \, 2^1 + \delta_{3,8} \, 2^2$$

Finally, for the above equation to be valid, $\delta_{1,8}$ must equal 1,

$\delta_{2,8}$ must equal 1 and $\delta_{3,8}$ must equal 1, and therefore the

$\sum_{i=1}^{3} \delta_{i,j} = 3$. Using Eq. (4), for X = 1, β_8 must equal 0, for X = 2, β_8 must equal 0 and for X = 3, β_8 must equal 1. The formation of the $\delta_{i,j}$'s from Eq. (3) and the β_j's from Eq. (4) for the preceding example in which N = 3, can be summarized as follows:

j	$\delta_{1,j}$	$\delta_{2,j}$	$\delta_{3,j}$	$\sum_{i=1}^{3} \delta_{i,j}$	β_j X=1	β_j X=2	β_j X=3
1	0	0	0	0	0	0	0
2	1	0	0	1	1	0	0
3	0	1	0	1	1	0	0
4	1	1	0	2	0	1	0
5	0	0	1	1	1	0	0
6	1	0	1	2	0	1	0
7	0	1	1	2	0	1	0
8	1	1	1	3	0	0	1

These tabular values may now be applied to Eq. (2) in which case the probability of <u>exactly</u> 1 success out of 3 events is expressed as:

$$P\binom{3}{1} = \beta_1 * (p_1^0 p_2^0 p_3^0 q_1^1 q_2^1 q_3^1) + \beta_2 * (p_1^1 p_2^0 p_3^0 q_1^0 q_2^1 q_3^1) + \beta_3 * (p_1^0 p_2^1 p_3^0 q_1^1 q_2^0 q_3^1)$$
$$+ \beta_4 * (p_1^1 p_2^1 p_3^0 q_1^0 q_2^0 q_3^1) + \beta_5 * (p_1^0 p_2^0 p_3^1 q_1^1 q_2^1 q_3^0) + \beta_6 * (p_1^1 p_2^0 p_3^1 q_1^0 q_2^1 q_3^0)$$
$$+ \beta_7 * (p_1^0 p_2^1 p_3^1 q_1^1 q_2^0 q_3^0) + \beta_8 * (p_1^1 p_2^1 p_3^1 q_1^0 q_2^0 q_3^0)$$

Since $\beta_1, \beta_4, \beta_6, \beta_7, \beta_8 = 0$ and $\beta_2, \beta_3, \beta_5 = 1$, the above equation reduces to:

$$P\binom{3}{1} = p_1^1 p_2^0 p_3^0 q_1^0 q_2^1 q_3^1 + p_1^0 p_2^1 p_3^0 q_1^1 q_2^0 q_3^1 + p_1^0 p_2^0 p_3^1 q_1^1 q_2^1 q_3^0$$

$$= p_1 q_2 q_3 + p_2 q_1 q_3 + p_3 q_1 q_2$$

Similarly,

$$P\binom{3}{2} = p_1 p_2 q_3 + p_1 p_3 q_2 + p_2 p_3 q_1$$

and

$$P\binom{3}{3} = p_1 p_2 p_3$$

Thus, the probability of <u>at least</u> 1 success out of 3 events is computed by

$$P\binom{3}{1} + P\binom{3}{2} + P\binom{3}{3}$$

$$= p_1 q_2 q_3 + p_2 q_1 q_3 + p_3 q_1 q_2 + p_1 p_2 q_3 + p_1 p_3 q_2 + p_2 p_3 q_1 + p_1 p_2 p_3$$

In instances in which only the <u>at least</u> case is required, the solution can be determined with the formation of fewer products, thus reducing the number of computations. This procedure can be utilized by taking advantage of complementary logic.

Since $$\sum_{i=0}^{N} P\binom{N}{i} = 1,$$

then $$\sum_{j=0}^{X-1} P\binom{N}{j} + \sum_{i=X}^{N} P\binom{N}{i} = 1;$$

Hence $$\sum_{i=X}^{N} P\binom{N}{i} = 1 - \sum_{j=0}^{X-1} P\binom{N}{j}$$

Thus, $P\binom{N}{X}$ can be expressed as

$$P\binom{N}{X} = \sum_{i=X}^{N} P\binom{N}{i} \tag{5}$$

or

$$P\binom{N}{X} = 1 - \sum_{j=0}^{X-1} P\binom{N}{j} \tag{6}$$

It follows that when $X < \frac{N}{2}$, then Eq. (6) should be used to compute the solution. In the preceding case for N = 3 and X = 1, if the only requirement had been the at least case, then the solution would be obtained using Eq. (6). Thus,

$$\sum_{i=1}^{3} P\binom{3}{i} = 1 - P\binom{3}{0}$$

$$= 1 - q_1 q_2 q_3 \; .$$

The above procedure requires only 1 product combination rather than the previously computed 7 combinations. The choice of using Eq. (5) or Eq. (6) can best be illustrated by a more realistic example in which case N = 18 and X = 9. If Eq. (5) were to be used, then $\sum_{j=9}^{18} \binom{18}{j}$ = 155,382 combinations would be required whereas the choice of Eq. (6) would require only $\sum_{j=0}^{8} \binom{18}{j}$ = 106,762 combinations.

A FORTRAN computer code, NX, has been written for efficiently computing the probability of at least, exactly or both cases as expressed in Eq. (2). This code, which takes advantage of the complementary logic condition where applicable, is given in Appendix A. In addition, a similar code in BASIC is also given in Appendix B for implementation on mini-computers utilizing this language.

The following sample problem was run using the FORTRAN code given in Appendix A:

Compute the probability of exactly 5, exactly 6, exactly 7 . . . exactly 13 successes out of 13 trials. The individual probabilities p_i are as follows:

$p_1 = 0.30$, $p_2 = 0.16$, $p_3 = 0.22$, $p_4 = 0.28$, $p_5 = 0.10$, $p_6 = 0.39$,

$p_7 = 0.33$, $p_8 = 0.51$, $p_9 = 0.44$, $p_{10} = 0.51$, $p_{11} = 0.68$,

$p_{12} = 0.73$, $p_{13} = 0.94$.

The code produced the following solution:

```
Probability of exactly  5 successes out of 13 trials = 0.237
Probability of exactly  6 successes out of 13 trials = 0.239
Probability of exactly  7 successes out of 13 trials = 0.165
Probability of exactly  8 successes out of 13 trials = 0.079
Probability of exactly  9 successes out of 13 trials = 0.026
Probability of exactly 10 successes out of 13 trials = 0.006
Probability of exactly 11 successes out of 13 trials = 0.001
Probability of exactly 12 successes out of 13 trials = 0.000
Probability of exactly 13 successes out of 13 trials = 0.000

Probability of at least 5 successes out of 13 trials = 0.754
```

This example required 7,099 product combinations to be formed and computed. Run times were 0.6 second and 2.0 seconds on a CDC Cyber 76 and a CDC Cyber 173, respectively. Using the code listing in Appendix B, the identical results were obtained from a WANG 2200-T mini-computer with a run time of approximately 83 minutes and from a WANG 2200-VP with a run time of 4.5 minutes.

For further information on the subject, the reader is referred to *Feller, William, "An Introduction to Probability Theory and It's Applications", New York, NY: John Wiley & Sons, 1968.*

III. CONCLUSIONS

A general expression is presented for computing the probability of X kills (successes) out of N trials, with unequal or equal individual probability of kill (success) values. Computer codes in both FORTRAN and BASIC are presented which yield the desired solutions using appropriate main-frame or mini-computers.

IV. ACKNOWLEDGEMENT

The authors would like to express their appreciation to Mr. Larry Losie for his invaluable assistance for formulating the general expressions given in Eqs. (2), (3), and (4).

APPENDIX A - FORTRAN Code Listing

Input Instructions for FORTRAN version of NX code

Card #	Format Type	Description
1	2I5	Number of trials N, number of successes X
2	16F5.1	N probabilities of success
3	I5	Code to select method of computation; = 1 to compute exactly case = 2 to compute both at least and exactly case = 3 to compute at least case

```
      PROGRAM NX    (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION I3(201), P(200), A(3), Z(2)
      INTEGER X, R3
    1 Z(1)=5HEVENT
      IZ=1
      Z(2)=6HEVENTS
      A(1)=7HEXACTLY
      A(3)=8HAT LEAST
      A(2)=10HBOTH TYPES
      READ (5,16) M,X
      IF (X.EQ.1) GO TO 2
      IZ=2
    2 IF (M.GE.X) GO TO 3
      STOP
    3 READ (5,17) (P(I),I=1,M)
      N=0
      DO 4 I=1,M
      IF (P(I).EQ.0.) GO TO 4
      N=N+1
      P(N)=P(I)
    4 CONTINUE
      IF (X.GT.N) GO TO 15
      T1=M-X
      IF (T1.NE.0.) GO TO 5
      T1=1.
    5 CONTINUE
      READ (5,16) R3
      GO TO (6,7,11), R3
    6 N1=X
      CALL D (N,N1,P,S)
      WRITE (6,18) X,Z(IZ),M,S
      STOP
    7 S2=0.
      DO 9 N1=X,N
      CALL D (N,N1,P,S)
      IF (N1.EQ.1) GO TO 8
      IZ=2
    8 WRITE (6,19) N1,Z(IZ),M,S
    9 S2=S2+S
      IF (X.EQ.1) GO TO 10
      IZ=2
   10 WRITE (6,20) X,Z(IZ),M,S2
      STOP
   11 S2=0.
```

```
      IF (2*X.LT.N) GO TO 13
      DO 12 N1=X,N
      CALL D (N,N1,P,S)
      S2=S2+S
   12 WRITE (6,20) X,Z(IZ),M,S2
      STOP
   13 DO 14 NN1=1,X$N1=NN1-1
      CALL D (N,N1,P,S)
      S2=S2+S
   14 CONTINUE
      SS2=1.-S2
      WRITE (6,20) X,Z(IZ),M,SS2
      STOP
   15 WRITE (6,21) X
      STOP
C
   16 FORMAT (2I5)
   17 FORMAT (16F5.1)
   18 FORMAT (5X,22HPROBABILITY OF EXACTLY,I5,A7,6HOUT OF,I4,1H=,F5.3)
   19 FORMAT (5X,22HPROBABILITY OF EXACTLY,I3,A7,6HOUT OF,I5,1H=,F5.3)
   20 FORMAT (5X,23HPROBABILITY OF AT LEAST,I3,A7,6HOUT OF,I4,1H=,F5.3)
   21 FORMAT (55H PROBABILITY OF THIS OCCURING IS ZERO  BECAUSE YOU DO N
     1,16HOT HAVE AT LEAST,F5.0,28H NON-ZERO PROBABILITY VALUES)
      END
      SUBROUTINE D (N,N1,P,S)
      DIMENSION P(200), I3(201)
    1 S=0.
      DO 2 I=1,N1
      I3(I)=1
    2 CONTINUE
      NN1=N1+1
      DO 3 I=NN1,N
      I3(I)=0
    3 CONTINUE
    4 A1=1.
      DO 6 I=1,N
      IF (I3(I).EQ.0) GO TO 5
      A1=A1*P(I)
      GO TO 6
    5 A1=A1*(1.-P(I))
    6 CONTINUE
      S=S+A1
      IF (N.NE.N1) GO TO 7
      RETURN
    7 I=0
```

```
 8 I=I+1
   IF (I3(N+1-I).GT.0) GO TO 9
   IF (I.NE.N) GO TO 8
   RETURN
 9 IF (I.LT.2) GO TO 10
   I4=N+1-I
   I3(I4)=0
   I4=I4+1
   I3(I4)=1
   GO TO 4
10 I9=N
   IF (I3(I9-1).LT.1) GO TO 13
   J=1
11 J=J+1
   IF (I3(I9-J).EQ.0) GO TO 12
   IF (J.NE.N-1) GO TO 11
   STOP
12 I9=I9-J
   IF (J-N1.NE.0) GO TO 13
   RETURN
13 I7=I9-1
   J=0
14 J=J+1
   IF (I3(I9-J).GT.0) GO TO 15
   IF (J.NE.I7) GO TO 14
   RETURN
15 I8=I9-J
   I3(I8)=0
   I8=I8+1
   I3(I8)=1
   IF (J.EQ.1) GO TO 4
   J=0
   N3=0
16 J=J+1
   IF (I3(I8+J).EQ.0) GO TO 17
   N3=N3+1
17 IF (I8+J-N.LT.0) GO TO 16
   L=0
18 L=L+1
   IF (I3(I8+L).NE.0) GO TO 4
   I3(I8+L)=1
   I3(N+1-L)=0
   IF (L.EQ.N3) GO TO 4
   GO TO 18
   END
```

APPENDIX B - BASIC Code Listing

```
10 REM  NX
20 COM I3(201),P(200),A$(3)60,Z$(4)
30% PROBABILITY OF EVENT ## IS
40% PROBABILITY OF EXACTLY  #### ###### OUT OF #### =  #.####
50% PROBABILITY OF AT LEAST #### ###### OUT OF #### =  #.####
60%########## ################# BEING CALCULATED, PLEASE BE PATIENT
70 Z$(1)="EVENT": Z$(2)="EVENTS": Z$(3) ="COMBINATION IS": Z$(4)="COMB
INATIONS ARE": Z=1: STR(Z$(3),16,1)=HEX(08)
80 PRINT HEX(03)
90 A$(1)="EXACTLY": A$(3)="AT LEAST": A$(2)="BOTH TYPES"
100 PRINT "PROGRAM IS DESIGNED FOR A MAXIMUM OF 200 EVENTS",HEX(0A0A)
110 INPUT "TOTAL NUMBER OF EVENTS",M: IF M<=0 THEN 110:     INPUT "NUMB
ER OF EVENTS FOR WHICH YOU WISH TO CALCULATE",X
120 IF X=1 THEN 130: Z=2
130 IF M>=X THEN 140: PRINT HEX(0A),"ERROR !!": GOTO 110
140 PRINT HEX(0A): FOR I= 1 TO M
150 PRINTUSING 30,I;:INPUT P(I): IF P(I)*(1-P(I))>=0 THEN 160:PRINT HE
X(0C),"ILLEGAL VALUE, TRY AGAIN      ": GOTO 150
160 NEXT I
170 PRINT HEX(03)
180 N=0: FOR I = 1 TO M: IF P(I)=0 THEN 190: N=N+1:P(N)=P(I)
190 NEXT I: IF X>N THEN 660
200 DEFFN'0: PRINT HEX(03)
210 PRINT "IF YOU WISH TO COMPUTE THE PROBABILITY OF  EXACTLY  X EVENT
S OUTOF N EVENTS, KEY IN A 1": PRINT HEX(0A)
220 PRINT "IF YOU WISH TO COMPUTE THE PROBABILITY OF AT LEAST  X EVENT
S OUTOF N EVENTS WITH EXACT INDIVIDUAL PROBABILITIES, KEY IN A 2": PRI
NT HEX(0A)
230 PRINT "IF YOU WISH TO COMPUTE THE PROBABILTY OF  AT LEAST  X EVENT
S OUTOF N EVENTS, KEY IN A 3"
240 PRINT HEX(0A0A)
250 INPUT "YOUR OPTION NUMBER",R3: PRINT HEX(03)
260 ON R3 GOTO 270,300,400:PRINT "ILLEGAL VALUE": GOTO 210
270 X1=X  : N1,N2=N: GOSUB '79: PRINTUSING 60,C4,Z$(Z1): PRINT : A=C4
280 N1=X: GOSUB '99: PRINTUSING 290,X,Z$(Z),M,S:STOP
290% PROBABILITY OF EXACTLY #### ###### OUT OF #### =  #.####
300 A=0: X1=X: N1,N2=N: GOSUB '69: PRINTUSING 60,A,Z$(Z1): PRINT
310 S2=0: FOR N1=X TO N: GOSUB '99
320 IF N1=1 THEN 330: Z=2
330 PRINTUSING 40,N1,Z$(Z),M,S
340 S2=S2+S: NEXT N1: S=0
350 IF N1=M THEN 370: N1=N1+1
360 PRINTUSING 40,N1,Z$(Z),M,S: GOTO 350
370 Z=1
380 PRINT HEX(0A): IF X=1 THEN 390: Z=2
390 PRINTUSING 50,X,Z$(Z),M,S2:STOP
400 S2=0: IF 2*X<=N THEN 430: X1=X: N1,N2=N: GOSUB '69
410 PRINTUSING 60,A,Z$(Z1):PRINT
```

```
420 FOR N1=X TO N: GOSUB '99: S2=S2+S: NEXT N1:  PRINTUSING 50,X,Z$(Z)
,M,S2: STOP
430 A,X1=0: N2=X-1:N1=N: GOSUB '69
440 PRINTUSING 60,A,Z$(Z1):PRINT
450 IF X<>0 THEN 460:S2=0 :GOTO 470
460 FOR N1=0 TO X-1: GOSUB '99: S2=S2+S: NEXT N1
470 PRINTUSING 50,X,Z$(Z),M,1-S2: STOP
480 DEFFN'99: S=0
490 FOR I = 1 TO N1: I3(I)=1: NEXT I
500 FOR I = N1+1 TO N: I3(I)=0: NEXT I
510 A1=1: FOR I = 1 TO N: IF I3(I)=0 THEN 520: A1=A1*P(I): GOTO   530
520 A1=A1*(1-P(I))
530 NEXT I: S=S+A1: IF N<>N1 THEN 540: RETURN
540 I=0
550 I=I+1: IF I3(N+1-I)>0 THEN 560: IF I<>N THEN 550: RETURN
560 IF I<2 THEN 570: I4=N+1-I: I3(I4)=0: I4=I4+1: I3(I4)=1: GOTO 510
570 I9=N: IF I3(I9-1)<1 THEN 600: J=1
580 J=J+1: IF I3(I9-J)<>0 THEN 580
590 I9=I9-J: IF J-N1<>0 THEN 600: RETURN
600 I7=I9-1: J=0
610 J=J+1: IF I3(I9-J)>0 THEN 620: IF J<>I7 THEN 610: RETURN
620 I8=I9-J: I3(I8)=0: I8=I8+1: I3(I8)=1: IF J=1 THEN 510: J,N3=0
630 J=J+1: IF I3(I8+J)=0 THEN 640: N3=N3+1
640 IF I8+J-N<0 THEN 630: L=0
650 L=L+1: IF I3(I8+L)<>0 THEN 510: I3(I8+L)=1: I3(N+1-L)=0: IF L=N3 T
HEN 510: GOTO 650
660 PRINT "PROBABILITY OF THIS OCCURING IS ZERO  BECAUSE YOU DO NOT HA
VE AT LEAST";X;" NON-ZERO PROBABILITY VALUES !": STOP
670 DEFFN'69: A=0: IF X1<>0 THEN 680: X1,A=1: IF X1<N2 THEN 680: IF N2
<=0 THEN 710: A=A+N: GOTO 710
680 IF X1<>1 THEN 690: A=A+N: X1=2: IF X1<N1 THEN 690: GOTO 710
690 FOR J=X1 TO N2: GOSUB '79: A=A+C4: X1=X1+1
700 NEXT J
710 Z1=4: IF A<> 1 THEN 720: Z1=3
720 RETURN
730 DEFFN'79: C1,C2,C3=1: IF N1<2 THEN 740: FOR I=2 TO N1: C1=C1*I: NE
XT I
740 IF N1-X1<2 THEN 760
750 FOR I=2 TO N1-X1: C2=C2*I: NEXT I
760 IF X1<2 THEN 780
770 FOR I=2 TO X1: C3=C3*I: NEXT I
780 C4=C1/(C2*C3)
790 Z1=4: IF C4<> 1 THEN 800: Z1=3
800 RETURN
```

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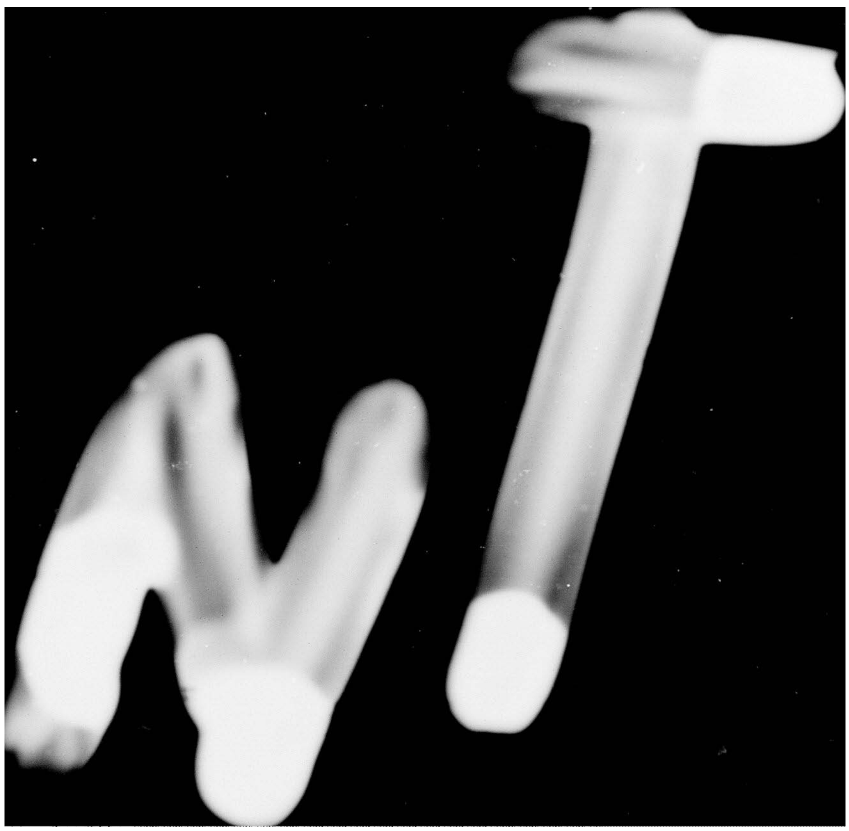

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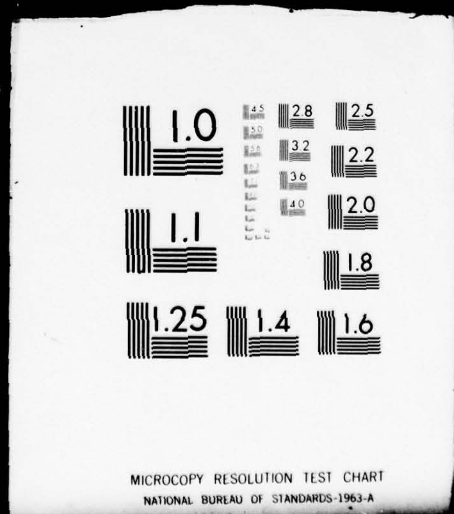

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DRDAR-BLV

12 June 1980

SUBJECT: Memorandum Report ARBRL-MR-02890, Jan 1979, by M. B. Danish and J. T. Hundley

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1. The subject report contains two computer programs. The authors have learned of an algorithm which accomplishes the same results, but much faster, as those obtained from the codes given in subject report. The algorithm was published in a formal report at the Naval Surface Weapons Center, Dahlgren, VA in 1975 but distribution was at that facility only, hence the information of importance was not known to these authors at BRL until after ARBRL-MR-02890 was published. It should be noted that the original algorithms used in the BRL version were reported on at BRL in May 1974.

2. In the interest of computing efficiency, we have utilized the algorithm developed by M. A. Thomas and A. E. Taub at the Naval Surface Weapons Center and prepared a FORTRAN and BASIC version to replace those versions originally appearing in ARBRL-MR-02890. The Thomas/Taub algorithm is extremely efficient and can be considered to be orders of magnitude faster than the BRL versions.

3. The reference report is NSWC/DL TN-DK-25/75, Binomial Trials with Variable Probabilities, August 1975, by M. A. Thomas and A. E. Taub.

H.W.Ege f. BF Armendt

2 Incls
as

BRADSHAW F. ARMENDT
Chief, Ground Mobility & Firepower Branch
Vulnerability/Lethality Division

80 6 19 120

```
      PROGRAM NX(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      COMMON T(20,21),R(20)
      READ (5,900)K1,N9
      IF(K1.LE.0)GOTO 330
      READ (5,901)(R(I9),I9=1,K1)
      T(1,1)=1-R(1)
      T(1,2)=R(1)
      DO 230 I9=2,K1
      K9=I9+1
      DO 220 J9=1,K9
      IF (J9.NE.1) GOTO 180
      T(I9,1)=T(I9-1,1)*(1-R(I9))
      GOTO 220
  180 IF(I9.EQ.K9) GOTO 210
      T(I9,J9)=T(I9-1,J9-1)*R(I9)+T(I9-1,J9)*(1-R(I9))
      GOTO 220
  210 T(I9,J9)=T(I9-1,J9-1)*R(J9)
  220 CONTINUE
  230 CONTINUE
      I9=K1
      S5=0
      IC1=N9+1
      IC2=K1+1
      DO 300 J9=IC1,IC2
      WRITE(6,902)J9-1,T(I9,J9)
      S5=S5+T(I9,J9)
  300 CONTINUE
      WRITE(6,903)N9,S5
  330 STOP
  900 FORMAT(2I10)
  901 FORMAT(10F10.5)
  902 FORMAT(' ','PROB OF EXACTLY ',I4,5X,F11.7)
  903 FORMAT('0','PROB OF AT LEAST ',I4,10X,F10.8)
      END
```

```
10 COM R(20): DIM T(20,21)
20 PRINT HEX(03)
30 INPUT "TOTAL NUMBER OF EVENTS",K1: IF K1<=0 THEN 20
40 INPUT "NUMBER OF EVENTS FOR WHICH YOU WISH TO CALCULATE",N9
50 PRINT HEX(0A)
60 FOR I9=1 TO K1:PRINT "P(";I9;")";: INPUT R(I9):NEXT I9
70 PRINT HEX(03)
80 PRINT "PLEASE BE PATIENT AS I AM COMPUTING FOR YOU"
90 T(1,1)=1-R(1)
100 T(1,2)=R(1)
110 FOR I9=2 TO K1
120 K9=I9+1
130 FOR J9=1 TO K9
140 IF J9<>1 THEN 160
150 T(I9,1)=T(I9-1,1)*(1-R(I9)):GOTO 200
160 IF I9=K9 THEN 190
170 T(I9,J9)=T(I9-1,J9-1)*R(I9)+T(I9-1,J9)*(1-R(I9))
180 GOTO 200
190 T(I9,J9)=T(I9-1,J9-1)*R(J9)
200 NEXT J9
210 NEXT I9
220 I9=K1
230 PRINT HEX(03): S5=0
240 FOR J9= N9+1 TO K1+1
250 PRINTUSING 270, J9-1,T(I9,J9)
260 S5=S5+T(I9,J9)
270 % PROB OF EXACTLY #### =  -###.#######    -###.######
280 NEXT J9
290 PRINT HEX(0A)
300 PRINTUSING 320,N9,S5
310 STOP
320% PROB OF AT LEAST ###  =     #.#######
```