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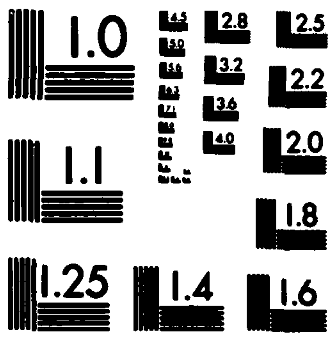
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DEVELOPING DOUBLE SAMPLING PLANS
FOR ATTRIBUTES TO MEET SAMPLE SIZE CRITERIA

Research Report No. 84-32

by

R.W. Rangarajan
K.B. Beitler
and
R.S. Leavenworth

# RESEARCH REPORT



Industrial & Systems
Engineering Department
University of Florida
Gainesville, FL 32611

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acceptable quality level

## ABSTRACT

This study reports on the development of a FORTRAN IV program to produce double sampling acceptance plans for attributes data. The plans must satisfy two points on an operating characteristic ~~OC~~ curve, the ~~AQL~~ point ($p_1$, 1-$\alpha$ alpha) and the rejectable quality level ~~RQL~~ point ($p_2$, $\beta$ beta). Two models are given. MODEL I has an additional constraint that the maximum value of the ASN must be less than or equal to the sample size for a corresponding single sampling plan. MODEL II relieves this constraint. In either case, the resulting plan has a minimum ASN evaluated at the quality level $p_1$ among all sampling plans satisfying the constraints.

## INTRODUCTION

Frequently double sampling plans are employed in lieu of single sampling plans for lot acceptance by attributes especially when lot or batch sizes are large. A number of systems of sampling plans are available the most recognized of which at least in the United States, are the MIL-STD-105D AQL systems and the Dodge-Romig LTD and AOQL systems.

In addition methods have been reported for developing tailored double sampling plans usually based on the specification of two points on an OC curve (the likelihood function). Two such procedures, largely taken from a Chemical Corps Engineering Agency (1953) publication, are contained in Tables 8-2 and 8-3 of Duncan (1974). These tables, based on the Poisson distribution, allow the tailoring of a plan to a Producer's Risk ($\alpha$) of 0.05 at a designated quality level $p_1$ and a Consumer's Risk of 0.10 at a designated level $p_2$. Plans may be found for which $n_2$, the second sample size equals $2n_1$ and where $n_2$ equals $n_1$. In either case the rejection number (cummulative) on both samples is taken to be the acceptance number on the second sample (cummulative), $c_2$, plus one.

In 1969 Guenther, following on some earlier work by Cameron (1952), developed what amounted to a brute-force algorithm for finding single sampling acceptance plans to satisfy two points on the likelihood function. The main difference between these two procedures is that while Cameron's procedure assured a plan with risk levels as close as possible to those designated for the quality levels $p_1$ and $p_2$, Guenther's procedure assures risk levels at least as good as those stipulated. In addition, Guenther's procedure allows the use of the hypergeometric, binomial or Poisson distributions assuming adequate tables are available.

In 1970 Guenther extended his work to double sampling plans. Again the algorithm is essentially brute force employing probability tables extensively. Unlike the Chemical Corps tables, however, the fixed relationship between $n_1$ and $n_2$ is not required nor does the Poisson have to be used. The disadvantage of his procedure is the laborious effort required if a plan is to be developed by hand calculation. The algorithms, however, are sufficiently simple to be programmed easily for the computer. Hailey (1980) provides an ANSI Standard FORTRAN program based on Guenther's algorithm which finds the minimum sample size single sampling plan.

In this study, a program is developed for finding double sampling plans and characteristics of the average sample size functions of the plans found are compared. The basic algorithm follows that of Guenther. However, an objective function is introduced as described in the following paragraphs.

## PROBLEM FORMULATION

When plotted as a function of p, the likelihood function L(p) of a sampling plan provides the operating characteristic (OC) curve for the plan. Using the binomial distribution as an example, L(p) for a double sampling plan is:

$$L(p) = \sum_{d_1 = 0}^{c_1} \binom{n_1}{d_1} p^{d_1} (1-p)^{n_1-d_1}$$

$$+ \sum_{d_1=C_1+1}^{r_1-1} \sum_{d_2=0}^{C_2-d_1} \binom{n_1}{d_1} \binom{n_2}{d_2} p^{d_1+d_2} (1-p)^{n_1+n_2-d_1-d_2} \qquad (1)$$

where:

$p$ = incoming proportion of nonconforming units

$n_1$ = first sample size

$n_2$ = second sample size

$c_1$ = acceptance number on first sample

$r_1$ = rejection number on first sample

$c_2$ = acceptance number on second sample (cumulative for $n_1+n_2$). The rejection number on the second sample, $r_2$, is $c_2+1$.

In this study, it is assumed that $r_1 = r_2 = c_2 + 1$. Thus the upper limit of the first summation, $(r_1 - 1)$ in the double summation portion of L(p) (the probability of acceptance on the second sample), may be replaced by $c_2$. By so doing a double sampling acceptance plan is fully described by the plan parameters $n_1$, $n_2$, $c_1$, and $c_2$.

Discussion of the algorithm for finding double sampling plans will break L(p) into its two parts, the probability of acceptance on the first sample, $P_a(n_1)$, and the probability of acceptance on the second sample, $Pa(n_2)$. Thus:

$$L(p) = Pa(n_1) + Pa(n_2)$$

where for the binomial case:

$$Pa(n_1) = B(c_1 \mid n_1, p) = \sum_{d_1=0}^{c_1} \binom{n_1}{d_1} p^{d_1} (1-p)^{n_1-d_1}$$

$$Pa(n_2) = BB(c_1, c_2 \mid n_1, n_2, p)$$

$$= \sum_{d_1=c_1+1}^{c_2} \sum_{d_2=0}^{c_2-d_1} \binom{n_1}{d_1}\binom{n_2}{d_2} p^{d_1+d_2} (1-p)^{n_1+n_2-d_1-d_2}$$

If two design points are designated on the likelihood function, ideally a single ($n_1$, $n_2$, $c_1$, $c_2$) set can be found yielding an OC curve which passes exactly through these points. This would suggest setting the likelihood function for each quality level equal to its respective probabilities and solving for a set (or several sets) which exactly satisfy the equations. However, since $n_1$, $n_2$, $c_1$ and $c_2$ all must be integer, it is doubtful that any set can be found which gives exact equality for both equations.

In recongnition of this fact the Cameron procedure for single sampling plans selects a plan which is as close as possible to the OC curve at the two points. The Guenther procedure rests on the formulation of inequality constraints that guarantee risk levels at least as good as those stipulated. It is the Guenther procedure which is used in this study.

The OC curve points selected are:

$p_1$ = An Acceptable Quality Level (AQL), following the definition in MIL-STD-105D, which should be accepted with a probability of at least $1-\alpha$, $\alpha$ being the Type I error risk.

$p_2$ = A Rejectable (poor) Quality Level (RQL) which should be accepted with no more than a low probability $\beta$ (Type II error risk).

These two design parameters therefore may be expressed as:

$$(p_1,\ 1-\alpha) \text{ and } (p_2,\ \beta).$$

The resulting constraint equations are:

$$L(p_1) \geq 1-\alpha \tag{2}$$

$$L(p_2) \leq \beta \tag{3}$$

Actually an infinite number of double sampling plans may be found which will satisfy these two inequalities. Thus some measure of performance must be specified in order to choose among them. The measure chosen in this study was to minimize the ASN when the lots are at the AQL, $p_1$.

The ASN function for a double sampling plan is:

$$ASN = n_1 + n_2 \, P(n_2)$$

where:

$P(n_2)$ is the probability of taking the second sample.

In binomial form,

$$ASN = n_1+n_2 \sum_{d_1=c_1+1}^{c_2} \binom{n_1}{d_1} p^{d_1} (1-p)^{n_1-d_1}$$

$$= n_1+n_2 \left[B(c_2|n_1, p) - B(c_1|n_1,p)\right]$$

Thus an objective function was introduced as follows:

Select $(n_1\ n_2, c_1, c_2)$ to:

$$\text{minimize } ASN(p_1) = n_1+n_2 \left[B(c_2|n_1,p_1) - B(c_1|n_1, p_1)\right] \quad (4)$$

Subject to equation (2) and (3).

Two models were formulated on the basis of equations (2), (3) and (4). Model I introduced an additional constraint, along the lines of MIL-STD-105D, guaranteeing that the maximum value of the ASN of the double sampling plan, ASNMAX, does not exceed the sample size $n_s$ of the minimum n and c for a single sampling plan satisfying equations (2) and (3). This value of $n_s$ is designated $n_s$*.

In order to study the effect that the ASNMAX constraint had on the value of the objective function, $ASN(p_1)$, the constraint was removed in Model II and Model II was run using the same design parameters. In this way one can assess, in terms of average number of items inspected, the penalty paid by requiring that the ASNMAX not exceed $n_s^*$.

## DEVELOPMENT OF THE ALGORITHM

The first step in developing a double sampling plan is to find the minimum single sampling plan ($n_s^*$, $c^*$) satisfying equation (2) and (3) where, for example:

$$L(p) = \sum_{d=0}^{c} \binom{n}{d} p^d (1-p)^{n-d} .$$

For any fixed value of c, there is some maximum value of n which will satisfy equation (2). If n is increased beyond this value, designated $n_u$ for an upper bound, equation (2) will be violated. Correspondingly, there is a minimum value of n, designated $n_\ell$, which just satisfies equation (3). Any value of n less than $n_\ell$ will produce a value of L(p2) greater than $\beta$.

Beginning with c equals 0, $n_\ell$ and $n_u$ are found by incrementing n one unit at a time. If the resulting values of $n_u$ is not greater than or equal to $n_\ell$, c is increased by one unit and the procedure repeated. Eventually at some value of c, $n_u > n_\ell$ is satisfied, the current value of c becomes $c^*$ and $n_s^*$ is set equal to $n_\ell$. Thus the minimum single sampling plan satisfying equations (2) and (3) is found. $n_s^*$ becomes an upper bound on $n_1$ for the double sampling plan and $c^*$ becomes a lower bound on $c_2$ where $c_1$ must be less than $c_2$.

The logic behind these limits is that, as $c_1$ approaches $c^*$, $n_1$ will approach $n_s^*$. If $c_1$ equals $c^*$, $n_1$ will equal $n_s^*$, $n_2$ will approach zero and $c_2$ will equal $c_1$. Thus any derived double sampling plan will degenerate to the corresponding single sampling plan.

The algorithm for deriving the double sampling plan employs equations (2) and (3) replacing the L(p) function with equation (1) or its Poisson or hypergeometric equivalents. This study concentrates on the binomial of equation (1) only. Initially $c_2$ is set equal to $c^*$ and $c_1$ is varied from 0 to $c_2-1$. On each iteration of $c_1$, $n_1$ is incremented from $c_1+1$ until the equation

$$B(c_1|n_1, p_2) < \beta$$

is just satisfied. This value of $n_1$ becomes $n_{1\ell}$, the lower feasible limit on $n_1$.

The algorithm then switches to the complete likelihood function, equation (1), searching to satisfy

$$L(p_1) > 1-\alpha$$

$$L(p_2) < \beta.$$

The computational procedure incorporates an integer bisection method in order increase efficiency.

An upper bound on $n_1$, $n_{1u}$, is obtained for the current value of $c_1$ from:

$$B(c_2|n_1, p_2) > 1-\alpha$$

with the constraint:

$$n_{1\ell} < n_{1u}.$$

The algorithm then switches to the complete likelihood function, equation (1), searching to satisfy:

$$n_{2\ell}: \; B(c_1|n_1, p_2) + BB(c_1,c_2|n_1,n_2,p_2) < \beta$$

$$n_{2u}: \; B(c_1|n_1,p_1) + BB(c_1,c_2|n_1,n_2,p_1) > 1-\alpha$$

with $n_{2\ell} < n_2 < n_{2u}$.

The lowest possible value for $n_2$ is $n_s^* - n_1$. Since it is necessary to set an upper bound on $n_2$, $n_{2u}$, in order to use a bisection search procedure, an arbitrary value of 1.5 times $n_1$ was used. This value worked sucessfully in all cases examined herein.

Once the bounds for $n_2$ have been set, the values of the maximum ASN (ASNMAX) and of the ASN evaluated at $p_1$ (ASN($p_1$)) are calcuated for each feasible value of $n_2$. These values along with $n_1$, $n_2$s and $n_{2\ell}$ form the output of the computer program.

## ANALYSIS AND CONDITIONS FOR OPTIMALITY

The double sampling plan parameters which may be varied are $n_1$, $n_2$, $c_1$, $c_2$, and $r_1$, five in all. Once minimum values for $c_1$ and $c_2$ have been established minimally satisfying the ($p_1$, $1-\alpha$) and ($p_2$, $\beta$) points on the OC curve, a number of conbinations of $n_1$ and $n_2$ values also will satisfy these constraints. Furthermore, it is possible to find feasible ranges of $n_1$ and $n_2$ conbinations for any values of $c_1$ and $c_2$ greater than the minimum ($c_1$,$c_2$) combination. Thus an infinite number of plans may be found satisfying the two OC curve points. They repesent, in effect, the solution of a pair of algebraic equations in five unknowns.

By introducing the MAXASN constraint, the number of feasible solutions is reduced as it is if the Dodge-Romig scheme of setting $r_1 = r_2 = c_2 +1$ is employed. It is the introduction of the objective of minimizing the ASN at the AQL, designated $p_1$, that makes it possible to select a single plan and allow the computer program to terminate. In order to accomplish this, the performance of the ASN ($p_1$) was analyzed by varying individually each of the main plan parameters $n_1$, $n_2$, $c_1$, and $c_2$ with $r_1$ set equal to $r_2 = c_2 + 1$.

Examples of this procedure are presented in Appendix I, SAMPLE PROGRAM RUNS. Values entered in each block (cell) are ASN($p_1$), ASNMAX, $n_1$ and $n_2$. Each block represents the results for a $c_1$, $c_2$ combination in the feasible region.

## Some General Constraints

The value of $c_1$ does not exceed the c* of the single sampling plan with the same OC curve. If $c_1$ equals c*, the double sampling plan will degenerate to the single sampling plan with $n_1$ = ns*, $n_2$=0, and $c_2$=$c_1$. Additionally, it is obvious from the ASN formula that, if $c_1$ is greater than c*, the ASN($p_1$) will be greater than ns* as will the ASNMAX. Hence the search on $c_1$ may be truncated at c*-1.

## Relationship of $\alpha$, $\beta$, $p_1$, and $p_2$

For fixed $\alpha$ and $\beta$, the acceptance number of a single sampling plan will remain constant for a constant discrimination ratio, D, defined as the ratio p2/p1. As p1 increases, the sample size of a single sampling plan decreases considerably. This can be explained by the fact that it is the absolute difference (p2-p1) that influences n, not the discrimination ratio. For example, for p1=0.02 and p2=0.10 the single sample size is approximately 38 with an acceptance number of 3. For p1=0.001 and p2=0.005, the same discrimination ratio, the single sample size is approximately 1,350 with an acceptance number of 3. This confirms that if (p2-p1) is small, n will be large and if (p2-p1) is large n will be small. Furthermore as the discrimination ratio decreases to 1.5, the acceptance number increases rather dramatically to 52. This result is verified by use of the Poisson approximation to the binomial and the methodology used to solve for single sampling plans therewith. See Cameron (1952).

Larger values of c1 result in a smaller range between n1s and n1l. As c1 increases for a specific value of c2, the lower bound on n1 increases. This in turn reduces the number of double sampling plans computed in each cell because the upper bound on n1, n1u, is dependent on c2, not on c1.

## Effect of ASNMAX Constraint, MODEL I

When the constraint ASNMAX <ns* is imposed, the values of ASN(p1) in the region where c2 exceeds c* become infeasible. An advantage of this property is that the search routine to locate the global minimum does not need to search the region where c2 exceeds c*. However, MODEL II, in which the ASNMAX constraint is not imposed, requires the evaluation of columns for c2 > c*. It is practically important to study the difference in minimum ASN(p1) in each case until a global minimum has been found. Thus, MODEL II searches for column minimums and selects the global minimum from that group. MODEL I needs only to look at the values for c2=c*.

## Behavior of ASN($p_1$) as a Function of $n_1$

Plotting of the values of ASN($p_1$) as a function of $n_1$ showed that it is a quasi-convex function of $n_1$. (Integerization of $n_1$ and $n_2$ may explain why the results were not purely convex) Thus a search for the minimum ASN($p_1$) needs only to continue one step beyond the point at which the minimum exists.

Behavior of ASN ($p_1$) as a Function of $c_1$.

In general, the ASN($p_1$) proved to be a quasi-convex function of $c_1$.

For a constant discrimination ratio, (D = p2/p1), MODEL I results showed that the minimum ASN(P1) occurs at the same value of c1 irrespective of the value of p1. Such is not the case with MODEL II.

The values of $c_1$ where the minimum ASN(p1) occurs is influenced by the ratio p2/p1. As the ratio decreases, the value of c1 increases. However this relationship also is affected by the magnitude of (p2-p1).

Table I.

| DESCRIMINATION RATIO (P2/P1) | VALUE of c1 AT min.ASN(p1) of column.(c2=c*) |
|---|---|
| 25 | 0 |
| 10 | 0 or 1 |
| 5 | 0 or 1 |
| 4 | 1 |
| 3 | 2 |
| 2.5 | 2 or 3 |

Table I indicates that as the ratio, D, decrease, the minimum ASN(p1) tends to increase. That is, the corresponding value of c1 becomes larger. As the ratio increases curves of ASN($p_1$) shift and become truncated constantly increasing from the first feasible solution rather than moving downward to a minimum before sweeping upward. In MODEL II, as c2 increases, the value c1 for the minimum ASN(p1) of each column may vary.

### Behavior of ASN($p_1$) as a Function of $c_2$

Plotting of the ASN($p_1$) values as a function of $c_2$ yielded quasi-convex results as well. However. there were substantially different results under the two models. When MODEL I (constrained ASNMAX) was employed, the minimum ASN(pl) value occured always for values of $c_2$ equal to c*. Under MODEL II, this was the case occassionally but not always.

### Impact of the ASNMAX Constraint

The main objective of the analysis of MODEL II was to evaluate the effect of the constraint ASNMAX<ns* on the objective function.

Table II shows the minimum ASN(pl) obtained from both models together with their ASNMAX values for some representative cases.

TABLE II

| VALUE OF p1 | VALUE OF p2 | RATIO OF p2/p1 | MODEL I ASN(P1) | MODEL I ASN MAX | MODEL II ASN(P1) | MODEL II ASN MAX | % OF REDUCTION |
|---|---|---|---|---|---|---|---|
| 0.001 | 0.04 | 4 | 179.8 | 185. | 149.1 | 232. | 17.1 |
| 0.02 | 0.8 | 4 | 75.4 | 86.5 | 73.2 | 115. | 2.23 |
| 0.005 | 0.125 | 25 | 19.9 | 27.1 | 19.9 | 27.1 | 0 |
| 0.005 | 0.05 | 10 | 67.1 | 98.9 | 67.1 | 98.9 | 0 |
| 0.04 | 0.2 | 5 | 21.6 | 31.5 | 21.6 | 31.5 | 0 |

As indicated, a reduction in ASN(pl) generally is obtained only when the D ratio is very low and/or the difference between p2 and pl is small. For a D ratio of 4 and (p2-pl) equals 0.03, a reduction in minimum ASN(pl) of 17.1% is obtained by dropping the constraint. However, when the difference between p2 and pl is increased to 0.6 with the same D, a reduction of only 2.9% in

ASN(p1) is seen, but seen at a cost of a substantial increase in ASNMAX. In the rest of the cases illustrated, no reduction in minimum ASN(p1) is obtained by eliminating the ASNMAX constraint. For these cases the D ratio was 5 or greater and (p2-p1) was 0.045 or greater. These results indicate that both the D ratio and the difference (p2-p1) affect ASNMAX but only when both are small.

Additionally, whenever a reduction in minimum ASN(p1) is obtained by dropping the constraint, the increase in corresponding ASNMAX value may be substantial. However the increase in ASNMAX may become smaller as the difference between p2 and p1 increases. In other words, as the difference between p2 and p1 decreases, the price to be paid for the protection against high ASNMAX's will start to increase.

## SUMMARY OF THE ALGORITHMS

### MODEL I

STEP 1. Compute smallest single sampling plan, (ns*, c*).

STEP 2. Set c2 = c*.

STEP 3. Incrementing on c1(0, 1, 2,..., c*-1):

- 3a. Compute feasible bounds on n1; i.e., n1l and n1u.
- 3b. Incrementing on n1(n1l, n1l+1,..., n1u) compute bounds on n2; i.e., n2l and n2u.
- 3c. Incrementing on n2(n2l, n2l+1,...,n2u) compute ASNMAX and ASN(p1).

### Condition for Optimality

Feasible values are those for which the likelihood constraints, (p1,1-$\alpha$) and (p2,$\beta$), and the ASNMAX constraints are satisfied. At each calculation in the feasible region, ASN(p1) is calculated and the optimal double sampling plan is the one with min ASN(pl). Because of convexity of ASN(pl), the algorithm shifts from cell to cell (value of $c_1$) whenever the current calculation (ASN(pl)'s) exceeds that for the previous calculation.

MODEL II

STEP 1. Compute the smallest single sampling plan (ns*, c*).

STEP 2 Incrementing on c2(c*, c*+1, c*+2,...):

STEP 3 Then incrementing on c1(0, 1, 2,,,,c*-1):

3a. Compute feasible bounds on n1; i.e; n1l and n1u.

3b. Incrementing on n1(n1l, n1l+1,..., n1u) compute bounds on n2; i.e; n2l and n2u.

3c. Incrementing on n2(n2l, n2l+1, n2l+2,...,n2u) compute ASN(pl).

Condition for Optimality

Feasible values are those for which the likelihood constraints are satisfied. At each calculation in the feasible region, ASN(pl) is calculated and the optimal double sampling plan is the one with min ASN(pl). Because of convexity of ASN(pl) the algorithm shifts from cell to cell (value of $c_1$) until the current calculation (ASN(pl)'s) exceeds that for the previous cell calculation. Similarily the algorithm shifts column to column (value of $c_2$) until the minimum ASN(pl) of the current column exceeds that for the previous column.

## COMPUTER CODE

The program originally was written in FORTRAN IV to run on a PDP 11-34 computer. Later it was modified to allow $r_1$ to be entered externally (rather than set at $r_2 = c_2+1$) and to run on a VAX 11-750 computer. The complete code is included in APPENDIX II.

As stated previously, the single sampling plan is computed using a brute force method; i.e: the search starts with an acceptance number of zero and the sample size is incremented by one at each iteration until L(p1) and L(p2) satisfy their respective inequalities. If the solved value of nl exceeds nu, no feasible solution exists for that value of c, c is incremented by one, and the search process for nl and nu starts anew. Depending on the input parameters ($\alpha$, $\beta$, p1 & p2), the single sample size may become very large thus requiring a large number of iterations to reach the first feasible solution. To reduce unnecessary computations, the user may input a "seed" number as a starting value of the single sample size. The closer the seed is to the true solution, the lesser the number of iterations required. However, the user must be very careful in entering a seed value. If a higher value of the seed than the true solution minimum ns is entered, the algorithm will converge to a single sampling plan with an acceptance number higher than that of minimum single sampling plan (the desired solution).

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# APPENDIX I

# SAMPLE PROGRAM RUNS

DEPT. OF ISE
UNIVERSITY OF FLORIDA

*****DOUBLE SAMPLING SYSTEM*****

ALPHA =0.0500 BETA =0.1000
PO =0.0100 P1 =0.0400

REJECTION NO. OF FIRST SAMPLE (R1) = C2+( 1)

S--------------------
ACCEPTANCE NO. (C) = 4
LOWER BOUND ON N (NS) = 198
UPPER BOUND ON N (NL) = 198

DOUBLE SAMPLING PLANS

FOR C1= 0 C2= 4

| | | | | |
|---|---|---|---|---|
| 136 | 62 | 62 | 186.8584 | 181.4362 |
| 137 | 61 | 61 | 187.0367 | 181.8368 |

DOUBLE SAMPLING PLANS

FOR C1= 1 C2= 4

| | | | | |
|---|---|---|---|---|
| 164 | 34 | 34 | 185.1312 | 179.7643 |
| 165 | 33 | 33 | 185.5088 | 180.3866 |

DOUBLE SAMPLING PLANS

FOR C1= 2 C2= 4

| | | | | |
|---|---|---|---|---|
| 183 | 15 | 15 | 189.1240 | 186.5909 |
| 184 | 14 | 14 | 189.7155 | 187.3789 |

DOUBLE SAMPLING PLANS

FOR C1= 3 C2= 4

| | | | | |
|---|---|---|---|---|
| 188 | 11 | 11 | 190.1723 | 188.8725 |
| 194 | 4 | 4 | 194.7896 | 194.3390 |

S--------------------
ACCEPTANCE NO. (C) = 5
LOWER BOUND ON N (NS) = 230
UPPER BOUND ON N (NL) = 262

DOUBLE SAMPLING PLANS

FOR C1= 0 C2= 5

| | | | | |
|---|---|---|---|---|
| 63 | 213 | 213 | 251.3808 | 162.9084 |
| 64 | 207 | 212 | 247.0489 | 162.1922 |
| 65 | 203 | 210 | 244.4871 | 162.3609 |

DOUBLE SAMPLING PLANS

FOR C1= 1 C2= 5

| | | | | |
|---|---|---|---|---|
| 101 | 180 | 183 | 232.8200 | 149.1270 |
| 102 | 174 | 181 | 229.4124 | 149.1608 |

DOUBLE SAMPLING PLANS

FOR C1= 2 C2= 5

| | | | | |
|---|---|---|---|---|
| 134 | 161 | 162 | 223.2362 | 157.9882 |
| 135 | 151 | 160 | 218.6858 | 157.8415 |
| 136 | 143 | 158 | 215.2449 | 157.9577 |

DOUBLE SAMPLING PLANS

FOR C1= 3 C2= 5

| | | | | |
|---|---|---|---|---|
| 166 | 149 | 155 | 220.4352 | 177.8430 |
| 167 | 127 | 151 | 213.3944 | 177.2542 |
| 168 | 114 | 148 | 209.6420 | 177.3490 |

DOUBLE SAMPLING PLANS

FOR C1= 4 C2= 5

| | | | | |
|---|---|---|---|---|
| 198 | 134 | 262 | 221.8151 | 202.6424 |
| 199 | 87 | 262 | 214.4609 | 202.0609 |
| 200 | 72 | 262 | 212.7945 | 202.5721 |

GLOBAL MINIMUM ASN(PO)= 149.16

CORRESPONDING N1 = 102

CORRESPONDING N2S = 174

CORRESPONDING C1 = 1

CORRESPONDING C2 = 5

DEPT. OF ISE
UNIVERSITY OF FLORIDA

*****DOUBLE SAMPLING SYSTEM*****

ALPHA =0.0500    BETA =0.1000
PO =0.0200    P1 =0.0800

REJECTION NO. OF FIRST SAMPLE (R1) = C2+( 1)

S---------------------
ACCEPTANCE NO.(C) = 4
LOWER BOUND ON N (NS) = 98
UPPER BOUND ON N (NL) = 99

DOUBLE SAMPLING PLANS

FOR C1= 0 C2= 4

| | | | | |
|---|---|---|---|---|
| 46 | 54 | 54 | 90.6816 | 78.5600 |
| 47 | 53 | 53 | 90.8418 | 79.3637 |

DOUBLE SAMPLING PLANS

FOR C1= 1 C2= 4

| | | | | |
|---|---|---|---|---|
| 62 | 39 | 39 | 86.5216 | 75.4389 |
| 63 | 38 | 38 | 86.8856 | 76.3481 |

DOUBLE SAMPLING PLANS

FOR C1= 2 C2= 4

| | | | | |
|---|---|---|---|---|
| 75 | 27 | 27 | 86.1676 | 79.6567 |
| 77 | 24 | 24 | 86.9210 | 81.3386 |

DOUBLE SAMPLING PLANS

FOR C1= 3 C2= 4

| | | | | |
|---|---|---|---|---|
| 87 | 16 | 16 | 90.2002 | 88.0654 |
| 88 | 14 | 15 | 90.7994 | 88.9571 |

S---------------------
ACCEPTANCE NO. (C) = 5
LOWER BOUND ON N (NS) = 114
UPPER BOUND ON N (NL) = 131

DOUBLE SAMPLING PLANS

FOR C1= 0 C2= 5

| | | | | |
|---|---|---|---|---|
| 31 | 105 | 108 | 124.7199 | 79.8665 |
| 32 | 100 | 106 | 121.2064 | 79.6080 |
| 33 | 96 | 105 | 118.5924 | 79.7088 |

DOUBLE SAMPLING PLANS

FOR C1= 1 C2= 5

| | | | | |
|---|---|---|---|---|
| 50 | 88 | 93 | 115.1913 | 73.2101 |
| 51 | 82 | 91 | 111.7191 | 73.2325 |

DOUBLE SAMPLING PLANS

FOR C1= 2 C2= 5

| | | | | |
|---|---|---|---|---|
| 66 | 81 | 84 | 111.4853 | 77.6491 |
| 67 | 72 | 81 | 107.4158 | 77.6818 |

DOUBLE SAMPLING PLANS

FOR C1= 3 C2= 5

| | | | | |
|---|---|---|---|---|
| 82 | 75 | 83 | 109.7731 | 87.7234 |
| 83 | 57 | 79 | 104.1007 | 87.4925 |
| 84 | 49 | 75 | 102.1335 | 87.9863 |

DOUBLE SAMPLING PLANS

FOR C1= 4 C2= 5

| | | | | |
|---|---|---|---|---|
| 98 | 63 | 131 | 109.3472 | 100.0915 |
| 99 | 35 | 131 | 105.3023 | 100.1993 |

GLOBAL MINIMUM ASN(PO)= 73.23

CORRESPONDING N1 = 51

CORRESPONDING N2S = 82

CORRESPONDING C1 = 1

CORRESPONDING C2 = 5

DEPT. OF ISE
UNIVERSITY OF FLORIDA

*****DOUBLE SAMPLING SYSTEM*****

ALPHA =0.0500 BETA =0.1000
P0 =0.0200 P1 =0.0600

REJECTION NO. OF FIRST SAMPLE (R1) = C2+( 1)

S--------------------
ACCEPTANCE NO. (C) = 7
LOWER BOUND ON N (NS) = 194
UPPER BOUND ON N (NL) = 200

DOUBLE SAMPLING PLANS

FOR C1= 0 C2= 7

| | | | | |
|---|---|---|---|---|
| 54 | 149 | 149 | 195.7031 | 152.9495 |
| 55 | 147 | 148 | 194.7807 | 153.6086 |

DOUBLE SAMPLING PLANS

FOR C1= 1 C2= 7

| | | | | |
|---|---|---|---|---|
| 80 | 124 | 124 | 187.7091 | 139.1258 |
| 81 | 122 | 123 | 186.9561 | 139.9612 |

DOUBLE SAMPLING PLANS

FOR C1= 2 C2= 7

| | | | | |
|---|---|---|---|---|
| 101 | 105 | 105 | 180.3470 | 135.4178 |
| 102 | 103 | 103 | 179.8239 | 136.3186 |

DOUBLE SAMPLING PLANS

FOR C1= 3 C2= 7

| | | | | |
|---|---|---|---|---|
| 121 | 86 | 86 | 174.2581 | 140.0145 |
| 122 | 84 | 85 | 174.0120 | 140.9156 |

DOUBLE SAMPLING PLANS

FOR C1= 4 C2= 7

| | | | | |
|---|---|---|---|---|
| 139 | 71 | 71 | 172.2300 | 148.9510 |
| 140 | 69 | 69 | 172.2892 | 149.8648 |

DOUBLE SAMPLING PLANS

FOR C1= 5 C2= 7

| | | | | |
|---|---|---|---|---|
| 157 | 57 | 57 | 174.6661 | 161.6958 |
| 158 | 53 | 55 | 174.4244 | 162.4568 |

DOUBLE SAMPLING PLANS

FOR C1= 6 C2= 7

| | | | | |
|---|---|---|---|---|
| 175 | 43 | 51 | 181.5391 | 176.6320 |
| 176 | 36 | 47 | 181.4739 | 177.3945 |

S ---------------------
ACCEPTANCE NO. (C) = 8
LOWER BOUND ON N (NS) = 215
UPPER BOUND ON N (NL) = 236

DOUBLE SAMPLING PLANS

FOR C1= 0 C2= 8

| | | | | |
|---|---|---|---|---|
| 44 | 197 | 199 | 234.9933 | 160.0134 |
| 45 | 193 | 198 | 232.0821 | 160.2446 |

DOUBLE SAMPLING PLANS

FOR C1= 1 C2= 8

| | | | | |
|---|---|---|---|---|
| 70 | 173 | 176 | 227.3926 | 140.8520 |
| 71 | 169 | 174 | 224.7274 | 141.3875 |

DOUBLE SAMPLING PLANS

FOR C1= 2 C2= 8

| | | | | |
|---|---|---|---|---|
| 92 | 156 | 157 | 220.2482 | 135.6124 |
| 93 | 151 | 156 | 217.1164 | 136.0340 |

DOUBLE SAMPLING PLANS

FOR C1= 3 C2= 8

| | | | | |
|---|---|---|---|---|
| 113 | 140 | 141 | 212.4149 | 139.6817 |
| 114 | 134 | 139 | 209.1393 | 140.0779 |

DOUBLE SAMPLING PLANS

FOR C1= 4 C2= 8

| | | | | |
|---|---|---|---|---|
| 134 | 120 | 125 | 203.5589 | 149.6677 |
| 135 | 113 | 123 | 200.4914 | 150.0802 |

DOUBLE SAMPLING PLANS

FOR C1= 5 C2= 8

| | | | | |
|---|---|---|---|---|
| 154 | 106 | 116 | 200.3735 | 163.1247 |
| 155 | 95 | 113 | 196.5552 | 163.3638 |

DOUBLE SAMPLING PLANS

FOR C1= 6 C2= 8

| | | | | |
|---|---|---|---|---|
| 174 | 91 | 125 | 200.3812 | 178.8247 |
| 175 | 75 | 118 | 196.7400 | 179.0665 |

DOUBLE SAMPLING PLANS

FOR C1= 7 C2= 8

| | | | | |
|---|---|---|---|---|
| 194 | 76 | 236 | 204.8341 | 195.9521 |
| 195 | 49 | 236 | 201.9844 | 196.2862 |

9-------------------
ACCEPTANCE NO. (C) = 9
LOWER BOUND ON N (NS) = 235
UPPER BOUND ON N (NL) = 273

DOUBLE SAMPLING PLANS

FOR C1= 0 C2= 9

| | | | | |
|---|---|---|---|---|
| 41 | 236 | 242 | 272.4937 | 173.9185 |
| 42 | 229 | 240 | 266.5910 | 172.9765 |
| 43 | 224 | 239 | 262.6524 | 173.0344 |

DOUBLE SAMPLING PLANS

FOR C1= 1 C2= 9

| | | | | |
|---|---|---|---|---|
| 66 | 221 | 222 | 273.3678 | 150.2853 |
| 67 | 212 | 220 | 265.8895 | 149.3582 |
| 68 | 205 | 218 | 260.2918 | 149.0869 |
| 69 | 200 | 217 | 256.5717 | 149.5144 |

DOUBLE SAMPLING PLANS

FOR C1= 2 C2= 9

| | | | | |
|---|---|---|---|---|
| 89 | 204 | 204 | 266.7397 | 142.7357 |
| 90 | 193 | 202 | 258.1279 | 141.8807 |
| 91 | 185 | 200 | 252.1336 | 141.7317 |
| 92 | 179 | 198 | 247.8829 | 142.0573 |

DOUBLE SAMPLING PLANS

FOR C1= 3 C2= 9

| | | | | |
|---|---|---|---|---|
| 111 | 186 | 188 | 256.2776 | 145.0258 |
| 112 | 173 | 186 | 247.1019 | 144.3393 |
| 113 | 164 | 184 | 241.0539 | 144.3170 |
| 114 | 157 | 182 | 236.5696 | 144.6165 |

DOUBLE SAMPLING PLANS

FOR C1= 4 C2= 9

| | | | | |
|---|---|---|---|---|
| 132 | 175 | 176 | 249.4611 | 154.0411 |
| 133 | 156 | 174 | 237.6933 | 153.0990 |
| 134 | 145 | 171 | 231.2966 | 153.1052 |

DOUBLE SAMPLING PLANS

FOR C1= 5 C2= 9

| | | | | |
|---|---|---|---|---|
| 153 | 154 | 171 | 237.1488 | 166.3868 |
| 154 | 132 | 167 | 226.1181 | 165.7449 |
| 155 | 121 | 164 | 221.0988 | 166.0171 |

DOUBLE SAMPLING PLANS

FOR C1= 6 C2= 9

| | | | | |
|---|---|---|---|---|
| 174 | 120 | 189 | 223.4432 | 181.0777 |
| 175 | 103 | 181 | 217.4335 | 181.2191 |

DOUBLE SAMPLING PLANS

FOR C1= 7 C2= 9

| | | | | |
|---|---|---|---|---|
| 194 | 112 | 273 | 224.6025 | 198.0900 |
| 195 | 81 | 273 | 217.1298 | 198.0276 |
| 196 | 70 | 273 | 215.1222 | 198.6775 |

DOUBLE SAMPLING PLANS

FOR C1= 8 C2= 9

| | | | | |
|---|---|---|---|---|
| 215 | 53 | 273 | 222.1338 | 215.9652 |
| 216 | 41 | 273 | 221.5181 | 216.7635 |

GLOBAL MINIMUM ASN(PO)= 135.42

CORRESPONDING N1 = 101

CORRESPONDING N2S = 105

CORRESPONDING C1 = 2

CORRESPONDING C2 = 7

DEPT. OF ISE
UNIVERSITY OF FLORIDA

*****DOUBLE SAMPLING SYSTEM*****

ALPHA =0.0500 BETA =0.1000
PO =0.0150 P1 =0.0450

REJECTION NO. OF FIRST SAMPLE (R1) = C2+( 1)

S--------------------
ACCEPTANCE NO.(C) = 7
LOWER BOUND ON N (NS) = 260
UPPER BOUND ON N (NL) = 266

DOUBLE SAMPLING PLANS

FOR C1= 0 C2= 7

| | | | | |
|---|---|---|---|---|
| 75 | 195 | 195 | 260.0430 | 207.2268 |
| 76 | 193 | 194 | 259.1314 | 207.8022 |

DOUBLE SAMPLING PLANS

FOR C1= 1 C2= 7

| | | | | |
|---|---|---|---|---|
| 108 | 164 | 164 | 250.0084 | 187.1743 |
| 109 | 162 | 162 | 249.2654 | 187.9875 |

DOUBLE SAMPLING PLANS

FOR C1= 2 C2= 7

| | | | | |
|---|---|---|---|---|
| 138 | 135 | 135 | 239.5929 | 184.0606 |
| 139 | 133 | 134 | 239.0794 | 184.9139 |

DOUBLE SAMPLING PLANS

FOR C1= 3 C2= 7

| | | | | |
|---|---|---|---|---|
| 164 | 111 | 111 | 232.4163 | 189.4726 |
| 165 | 109 | 109 | 232.1787 | 190.3486 |

DOUBLE SAMPLING PLANS

FOR C1= 4 C2= 7

| | | | | |
|---|---|---|---|---|
| 188 | 90 | 90 | 229.9069 | 201.1494 |
| 189 | 87 | 88 | 229.5068 | 201.8962 |

DOUBLE SAMPLING PLANS

FOR C1= 5 C2= 7

| | | | | |
|---|---|---|---|---|
| 211 | 72 | 72 | 233.1982 | 217.1050 |
| 212 | 68 | 70 | 232.9633 | 217.8536 |

DOUBLE SAMPLING PLANS

FOR C1= 6 C2= 7

| | | | | |
|---|---|---|---|---|
| 234 | 59 | 64 | 242.9257 | 236.2712 |
| 235 | 51 | 60 | 242.7148 | 236.9932 |

S--------------------
ACCEPTANCE NO. (C) = 8
LOWER BOUND ON N (NS) = 287
UPPER BOUND ON N (NL) = 314

DOUBLE SAMPLING PLANS

FOR C1= 0 C2= 8

| | | | | |
|---|---|---|---|---|
| 59 | 264 | 265 | 314.4307 | 214.7717 |
| 60 | 260 | 263 | 311.5352 | 215.0103 |

DOUBLE SAMPLING PLANS

FOR C1= 1 C2= 8

| | | | | |
|---|---|---|---|---|
| 93 | 235 | 235 | 306.1528 | 188.7529 |
| 94 | 231 | 233 | 303.5039 | 189.3262 |

DOUBLE SAMPLING PLANS

FOR C1= 2 C2= 8

| | | | | |
|---|---|---|---|---|
| 124 | 205 | 207 | 291.8433 | 182.4429 |
| 125 | 200 | 206 | 288.7336 | 182.8303 |

DOUBLE SAMPLING PLANS

FOR C1= 3 C2= 8

| | | | | |
|---|---|---|---|---|
| 152 | 183 | 185 | 281.3353 | 187.6786 |
| 153 | 177 | 183 | 278.0829 | 188.0451 |

DOUBLE SAMPLING PLANS

FOR C1= 4 C2= 8

| | | | | |
|---|---|---|---|---|
| 179 | 164 | 166 | 273.5826 | 200.6032 |
| 180 | 156 | 164 | 269.9618 | 200.8872 |

DOUBLE SAMPLING PLANS

FOR C1= 5 C2= 8

| | | | | |
|---|---|---|---|---|
| 206 | 143 | 151 | 268.2267 | 218.5081 |
| 207 | 131 | 148 | 264.0007 | 218.6513 |

DOUBLE SAMPLING PLANS

FOR C1= 6 C2= 8

| | | | | |
|---|---|---|---|---|
| 232 | 157 | 163 | 277.2705 | 240.3717 |
| 233 | 117 | 157 | 266.7340 | 239.3440 |
| 234 | 101 | 151 | 263.1187 | 239.5680 |

DOUBLE SAMPLING PLANS

FOR C1= 7 C2= 8

| | | | | |
|---|---|---|---|---|
| 260 | 80 | 314 | 271.3427 | 262.1125 |
| 261 | 63 | 314 | 269.9318 | 262.6904 |

S--------------------

ACCEPTANCE NO. (C) = 9
LOWER BOUND ON N (NS) = 314
UPPER BOUND ON N (NL) = 363

DOUBLE SAMPLING PLANS

FOR C1= 0 C2= 9

| | | | | |
|---|---|---|---|---|
| 55 | 316 | 322 | 364.4188 | 233.3808 |
| 56 | 309 | 320 | 358.5363 | 232.4478 |
| 57 | 303 | 319 | 353.6355 | 231.9713 |
| 58 | 298 | 317 | 349.7147 | 231.9728 |

DOUBLE SAMPLING PLANS

FOR C1= 1 C2= 9

| | | | | |
|---|---|---|---|---|
| 89 | 291 | 294 | 361.2587 | 201.4461 |
| 90 | 283 | 292 | 354.7504 | 200.8535 |
| 91 | 276 | 290 | 349.1775 | 200.5675 |
| 92 | 270 | 289 | 344.5428 | 200.6042 |

DOUBLE SAMPLING PLANS

FOR C1= 2 C2= 9

| | | | | |
|---|---|---|---|---|
| 120 | 264 | 269 | 349.1373 | 191.0035 |
| 121 | 255 | 267 | 342.3050 | 190.6154 |
| 122 | 247 | 265 | 336.3438 | 190.4330 |
| 123 | 241 | 263 | 332.1181 | 190.7493 |

DOUBLE SAMPLING PLANS

FOR C1= 3 C2= 9

| | | | | |
|---|---|---|---|---|
| 149 | 243 | 248 | 337.9465 | 194.2755 |
| 150 | 231 | 246 | 329.6002 | 193.7339 |
| 151 | 222 | 244 | 323.5883 | 193.7005 |
| 152 | 215 | 242 | 319.1306 | 194.0067 |

DOUBLE SAMPLING PLANS

FOR C1= 4 C2= 9

| | | | | |
|---|---|---|---|---|
| 177 | 226 | 232 | 327.9336 | 206.0636 |
| 178 | 209 | 229 | 317.5687 | 205.3329 |
| 179 | 197 | 227 | 310.5440 | 205.1960 |
| 180 | 189 | 224 | 306.1929 | 205.5502 |

DOUBLE SAMPLING PLANS

FOR C1= 5 C2= 9

| | | | | |
|---|---|---|---|---|
| 205 | 198 | 223 | 312.6136 | 222.6100 |
| 206 | 178 | 220 | 302.7364 | 222.1069 |
| 207 | 166 | 216 | 297.2081 | 222.2803 |

DOUBLE SAMPLING PLANS

FOR C1= 6 C2= 9

| | | | | |
|---|---|---|---|---|
| 232 | 200 | 248 | 313.9585 | 243.8767 |
| 233 | 156 | 241 | 296.9233 | 242.4273 |
| 234 | 139 | 233 | 290.9528 | 242.5471 |

DOUBLE SAMPLING PLANS

FOR C1= 7 C2= 9

| | | | | |
|---|---|---|---|---|
| 260 | 126 | 363 | 294.2362 | 264.7458 |
| 261 | 106 | 363 | 289.8002 | 265.0618 |

DOUBLE SAMPLING PLANS

FOR C1= 8 C2= 9

| | | | | |
|---|---|---|---|---|
| 287 | 82 | 363 | 297.9774 | 288.5138 |
| 288 | 63 | 363 | 296.4333 | 289.1825 |

GLOBAL MINIMUM ASN(PO)= 184.06

CORRESPONDING N1 = 138

CORRESPONDING N2S = 135

CORRESPONDING C1 = 2

CORRESPONDING C2 = 7

# APPENDIX II

## FORTRAN IV PROGRAM

```
C       QUALITY CONTROL DOUBLE SAMPLING PROGRAM TO ANALYSE
C       DOUBLE SAMPLING PLANS. ASN(PO) AND ASNMAX.
C       BINOMIAL AND POISON PROBALITY DISTRIBUTIONS USED.
C
C       PROGRAMED BY R. WAREN RANGARAJAN
C       INDUSTRIAL AND SYSTEMS ENGINEERING DEPARTMENT
C       UNIVERSITY OF FLORIDA
C       GAINESVILLE, FLORIDA 32611
C
        DOUBLE PRECISION SUMLOG
        INTEGER C,C1,C2,C1MIN,C2MIN,R1,R11
        BYTE STING(8)
        COMMON/BLK1/N2S,N2L
        COMMON/BLK2/PS,PL
        COMMON/BLK3/N1
        COMMON/BLK4/ALPHA,BETA
        COMMON/BLK5/PO,P1
        COMMON/BLK6/C1,C2
        COMMON/BLK7/SUMLOG(2500)
        COMMON/BLK8/N
        COMMON/BLK9/C2MAX,C1MAX(15)
        COMMON/BLK10/NS,NL
        COMMON/BLK11/ASN,ASNMAX
C
C
        WRITE(5,*) ' NAME OF OUTPUT FILE?'
        READ(5,1) STING
      1 FORMAT(10A1)
C
        CALL ASSIGN (1,STING)
C
C       BEGINNING INITIALIZATION
C
        N=0
        C2=1000
        ASNMIN=15000.
        C=-1
C
C       INPUT FORMAT
C
     15 WRITE (5,16)
     16 FORMAT (///' CODES FOR SELECTING APPR. PROB. DIST.'//
       115X,'BINOMIAL',12X,'=1',
       2/15X,'POISSON',13X,'=2')
        READ (5,*) K
        IF(K.GT.2.OR.K.LT.1) GOTO 15
     22 WRITE(5,21)
     21 FORMAT(10X,'SELECT'/16X,'SAMPLE PLANS ONLY =1'
       1/16X,'ASN VALUES ONLY =2'
       2/16X,'OR BOTH            =3')
        READ(5,*) KOPT
        IF(KOPT.GT.3.OR.KOPT.LT.1) GOTO 22
        WRITE (5,17)
     17 FORMAT(10X,'INPUT ALPHA ')
        READ (5,*) ALPHA
        WRITE (5,18)
     18 FORMAT(10X,'INPUT BETA ')
```

```
              READ (5,*) BETA
      C
              WRITE (5,51)
           51 FORMAT(10X,'INPUT PO ')
              READ (5,*) PO
              WRITE(5,52)
           52 FORMAT(10X,'INPUT P1 ')
              READ (5,*) P1
              WRITE(5,58)
           58 FORMAT( 5X,'INPUT A SEED FOR SINGLE SAMPLING NO.'//
             1'          IF NO SEED AVAILABLE ENTER ZERO AS THE SEED VALUE')
              READ(5,*) NS
              WRITE(5,59)
           59 FORMAT( 5X,'INPUT A VALUE FOR (R1-C2) '//
             1'          IF R1=C2 THEN THE VALUE WOULD BE 0'//
             2'          IF R1)C2 THEN THE VALUE WOULD BE A POSITIVE NO.'//
             3'          IF R1(C2 THEN THE VALUE WOULD BE A NEGATIVE NO.')
              READ(5,*) R11
      C
              MC1=10.0/(P1/PO)
              WRITE (1,53)
           53 FORMAT(///10X,'DEPT. OF ISE  '
             1/,10X,'UNIVERSITY OF FLORIDA '/
             2/5X,5('*'),'DOUBLE SAMPLING SYSTEM',5('*'),2X,/)
              WRITE (5,54) ALPHA,BETA,PO,P1
              WRITE (1,54) ALPHA,BETA,PO,P1
           54 FORMAT(//10X,'ALPHA =',F6.4,5X,'BETA =',F6.4,
             1/10X,'PO =',F6.4,8X,'P1 =',F6.4)
              WRITE(5,55) R11
              WRITE(1,55) R11
           55 FORMAT(/5X,'REJECTION NO. OF FIRST SAMPLE (R1) = C2+(',I3,')')
            5 C=C+1
      C
      C       SINGLE SAMPLING PROCEDURE BEGINS
      C
              KK1=C+1
           10 NS=NS+1
      C
      C       COMPUTATION OF LOWER BOUND OF SINGLE SAMPLING PLAN
      C
              IF(K.EQ.1) CALL PROBS1(NS,P1,C,BXLEC,N)
              IF(K.EQ.2) CALL PROBS2(NS,P1,C,BXLEC,N)
              IF(BXLEC.GT.BETA) GOTO 10
              NLT=NS-5
              NL=MAXO(1,NLT)
      C
      C       COMPUTATION OF UPPER BOUND OF SINGLE SAMPLING PLAN
      C
           20 NL=NL+1
              IF(K.EQ.1) CALL PROBS1(NL,PO,C,BXLEC)
              IF(K.EQ.2) CALL PROBS2(NL,PO,C,BXLEC)
              IF(BXLEC.GE.(1-ALPHA)) GOTO 20
              NL=NL-1
      C
      C       TEST FOR FEASIBILITY
      C
              IF(NS.GT.NL) GOTO 5
```

```
      WRITE (5,90)
      WRITE(1,90)
   90 FORMAT(//10X,'SINGLE SAMPLING PLAN '/'+',9X,21('_'))
      WRITE(5,91) C,NS,NL
      WRITE(1,91) C,NS,NL
   91 FORMAT(10X,'ACCEPTANCE NO.(C) =',I2
     1,/10X,'LOWER BOUND ON N (NS) =',I4
     2,/10X,'UPPER BOUND ON N (NL) =',I4)
C
C     COMPUTATION OF DOUBLE SAMPLING PLAN BEGINS: FOR EACH VALUE OF C2
C
      IF(C.LT.C2) MC=C+MC1-1
      C2=C
C
      R1=C2+R11
C
      DO 100 K1=1,C2
         C1=K1-1
C
C     CALL SUBROUTINE TO COMBUTE THE FIRST SAMPLE NUMBER
C
         CALL TRY1(NTRY,C1,P1,NS,BETA,K)
         N1=NTRY
         IF(NTRY.GT.NS) GOTO 600
C
C
         WRITE(5,161)
         WRITE(1,161)
  161    FORMAT(/10X,'DOUBLE SAMPLING PLANS',/)
         WRITE(5,160) C1,C2
         WRITE(1,160) C1,C2
  160    FORMAT(/10X,'FOR  C1=',I2,2X,'C2=',I2,//)
C
         NTEMP=N1
         IF(KOPT.EQ.1) WRITE(5,170)
         IF(KOPT.EQ.3) WRITE(5,175)
  175    FORMAT(10X,'(N1)',3X,'(N2S)',3X,'(N2L)',4X,'ASNMAX',5X,'ASN'
     1   /)
  170    FORMAT(11X,'(N1)',10X,' (N2S)     <   N2   <     (N2L)',8X,'PS',
     1   10X,'PL'//)
         NTEMP1=NS
C
C     COMPUTATION OF SECOND SAMPLE FOR EACH VALUE OF FIRST SAMPLE
C
         ASN=FLOAT(NS)*10
         DO 190 IZ=NTEMP,NTEMP1
            I=IZ
C
C     CALL SUBROUTINE TO COMPUTE SECOND SAMPLE
C
            CALL TRY2(NS,NL,K,I,R1)
            IF(KOPT.NE.1) GOTO 500
            WRITE (5,185) I,N2S,N2L,PS,PL
            WRITE(1,185) I,N2S,N2L,PS,PL
  185       FORMAT(10X,I4,13X,I4,'    <   N2   <      ',I4,4X,F8.6,8X,F8.6)
            GOTO 190
C
```

```
C       TEST FOR FEASIBILITY
C
  500          IF(N2S.GT.N2L) GOTO 190
               IF(N2S.LT.(C2-C1).OR.I.LE.C2) GOTO 190
               ASNTEM=ASN
C
C       CALL SUBROUTINE TO COMPUTE ASN(PO) AND ASNMAX VALUES
C
               CALL ASNN(MC,NS,K,I,KOPT,C1MIN,C2MIN,N1MIN,N2MIN,ASNMIN)
               IF(KOPT.NE.3) GOTO 190
               WRITE(5,410)I,N2S,N2L,ASNMAX,ASN
               WRITE(1,410)I,N2S,N2L,ASNMAX,ASN
  410          FORMAT(10X,I3,4X,I3,5X,I3,5X,2(F8.4,3X))
               IF(ASN.GT.ASNTEM) GOTO 100
  190     CONTINUE
C
C
  100 CONTINUE
C
  600 IF(C.LT.MC) GOTO 5
      WRITE(1,601) ASNMIN,N1MIN,N2MIN,C1MIN,C2MIN
      WRITE(5,601) ASNMIN,N1MIN,N2MIN,C1MIN,C2MIN
  601 FORMAT( 10X,'GLOBAL MINIMUM ASN(PO)=',F8.2,//
     110X,'CORRESPONDING N1         =',I5//
     210X,'CORRESPONDING N2S        =',I5//
     310X,'CORRESPONDING C1         =',I2//
     410X,'CORRESPONDING C2         =',I2)
C
C
      STOP
      END
```

```
C
C
C
C
      SUBROUTINE TRY1(NTRY,C1,P,NL,BETA,K)
C
C     THIS SUBROUTINE COMPUTES FIRST SAMPLE NUMBER OF DOUBLE
C     SAMPLING PLAN BY AN INTEGER FORM OF BISECTION METHOD
C
      INTEGER C1
C
C
      NLARGE=NL
      NSMALL=0
C
    5 NTRY=(NSMALL+NLARGE)/2.0
C     CALL APPROPRIATE PROBAILITY SUBROUTINE FOR PROB. CALCULATIONS
   10 IF(K.EQ.1) CALL PROBS1(NTRY,P,C1,BXLEC)
      IF(K.EQ.2) CALL PROBS2(NTRY,P,C1,BXLEC)
      IF(BXLEC.LE.BETA) GOTO 50
      NSMALL=NTRY
      GOTO 25
   50 NLARGE=NTRY
   25 IF(NSMALL.NE.(NLARGE-1)) GOTO 5
      NTRY=NLARGE
      RETURN
      END
```

```
C
C
C
C
      SUBROUTINE PROBD1(N1,N2,P,DPROB,K,R1)
C
C     THIS SUBROUTINE COMPUTES DOUBLE PROBABILITIES FOR
C     COMPUTING SECOND SAMPLE NUMBER OF DOUBLE SAMPLING NUMBER
C
      COMMON/BLK6/C1,C2
      INTEGER C1,C2,R1
C
C
      IF(K.EQ.1) CALL PROBS1(N1,P,C1,BXLEC)
      IF(K.EQ.2) CALL PROBS2(N1,P,C1,BXLEC)
      DPROB=BXLEC
      TEMP=BXLEC
      NTEMP=C1+1
      KTEMP=R1-1
      DO 10 IX=NTEMP,KTEMP
         I=IX
         J=C2-I
         IF(K.EQ.1) CALL PROBS1(N1,P,I,BXLEC)
         IF(K.EQ.2) CALL PROBS2(N1,P,I,BXLEC)
         PROB1=BXLEC-TEMP
         TEMP=BXLEC
         IF(K.EQ.1) CALL PROBS1(N2,P,J,BXLEC)
         IF(K.EQ.2) CALL PROBS2(N2,P,J,BXLEC)
         DPROB=DPROB+(PROB1*BXLEC)
   10 CONTINUE
C
      RETURN
      END
```

```
C
C
C
C
      SUBROUTINE TRY2(NS, NL, K, J, R1)
C
C     THIS SUBROUTINE COMPUTES THE SECOND SAMPLE NUMBER OF
C     THE DOUBLE SAMPLING NUMBER BY AN INTEGER BISECTION
C     METHOD. SEVERAL TESTS ARE DONE TO LOCATE THE PARAMETER
C     AT ITS TRUE POSITION.
C
      INTEGER C1, C2, R1
C
      COMMON/BLK1/N2S, N2L
      COMMON/BLK2/PS, PL
      COMMON/BLK3/N1
      COMMON/BLK4/ALPHA, BETA
      COMMON/BLK5/PO, P1
      COMMON/BLK6/C1, C2
C
      K1=C1+1
C
C     SET LIMITS FOR COMPUTING N2S
C
      NSMALL=NS-J
      NLARGE=NSMALL
C
C     INDEXING TO SPECIFY WHAT BOUND (N2S OR N2L) IS BEING
C     COMPUTED
C
      I=1
C
C     INITIAL TEST AT EACH LIMIT
C
      CALL PROBD1(J, NSMALL, P1, DPROB, K, R1)
      IF(DPROB.LE.BETA) GOTO 55
C
C     BISECTION METHOD
C
      NLARGE=NL
    5 NTRY=(NSMALL+NLARGE)/2.0
      GOTO (10, 20), I
C
   10 CALL PROBD1(J, NTRY, P1, DPROB, K, R1)
      IF(DPROB.LE.BETA) GOTO 50
      GOTO 15
   20 CALL PROBD1(J, NTRY, PO, DPROB, K, R1)
      IF(DPROB.LT.(1-ALPHA)) GOTO 50
   15 NSMALL=NTRY
      GOTO 25
   50 NLARGE=NTRY
   25 IF((NLARGE-NSMALL).GT.1) GOTO 5
C
C     CHECK THE INDEX TO FIND WHERE THE PROCESS IS
C
      GOTO (55, 60), I
C
```

```
C      CHANGE THE INDEX AFTER N2S COMPUTATION
C
    55 I=I+1
C
C      TESTING EACH POSSIBLE CASES TO LOCATE
C      THE LOWER BOUND AT ITS TRUE POSITION
C
       N2S=MAX0(0,NLARGE)
       CALL PROBD1(J,NLARGE,P1,DPROB,K,R1)
       PS=DPROB
       MTEMP=NLARGE-5
       NSMALL=MAX0(0,MTEMP)
       NLARGE=NL
       GOTO 5
    60 N2L=NSMALL
       CALL PROBD1(J,NSMALL,P0,DPROB,K,R1)
       PL=DPROB
       CALL PROBD1(J,NLARGE,P0,DPROB,K,R1)
       IF(DPROB.GE.(1-ALPHA)) N2L=NLARGE
       IF(DPROB.GE.(1-ALPHA)) PL=DPROB
C
C
   110 RETURN
       END
```

```
C
C
C
C
      SUBROUTINE PROBS1(NN,P,C,BXLEC)
C
C     THIS SUBROUTINE COMPUTES CUMULATIVE BINOMIAL
C     PROBABILITIES
C
      INTEGER C
      DOUBLE PRECISION SUMLOG
      COMMON/BLK7/SUMLOG(1500)
      COMMON/BLK8/N
C
C
      Q=1.-P
C
C         BINOMIAL PROB. WHEN C=0
C
      CSUMS=Q**NN
C     WRITE(6,500) CSUMS
      IF (C.EQ.0) GOTO 333
C
C      AVOID RECOMPUTING SUMLOG(I)'S ALREADY IN MEMORY
C
      IF (N-NN) 100,211,211
  100 M=N+1
C
C          COMPUTE N SUMLOGS-EQUIVALENT TO N-FACTORIAL
C
      IF (M.GT.1) GOTO 110
      SUMLOG(1)=0.
      IF(NN.LE.1) GOTO 211
      M=2
  110 DO 111 I=M,NN
          SUMLOG(I)=DLOG10(DFLOAT(I))+SUMLOG(I-1)
  111 CONTINUE
C
C          COMPUTE C SUMS-EQUIVALENT TO SSUM OF PROB.COMPIN.
C          I.E. CUMULATIVE BINOMIAL DISTRIBUTION COMPUTATION
C
  211 IF(NN.GT.N) N=NN
C
C          DETERMINE BEST NUMBER HANDLING LOOP
C
      IF (NN.GT.300) GOTO 300
      DO 222 K=1,C
          CSUMS=10.**(SUMLOG(NN)-SUMLOG(NN-K)-SUMLOG(K))
     1                    *P**K*Q**(NN-K)+CSUMS
  222 CONTINUE
C     WRITE(6,501) CSUMS
C 501 FORMAT(5X,'XXX',F8.6)
      GOTO 333
C
C          LOOP FOR LARGE EXPONENTS
C
  300 DO 322 K=1,C
```

PROBS1

```
                CSUMS=10.**(SUMLOG(NN)-SUMLOG(NN-K)-SUMLOG(K)
         1       +K*DLOG10(DBLE(P))+(NN-K)*DLOG10(DBLE(Q)))+CSUMS
      C         WRITE(6,501) CSUMS
      C  500    FORMAT(10X,F8.6)
         322 CONTINUE
      C
         333 BXLEC = CSUMS
             RETURN
             END
```

```
C
C
C
C
      SUBROUTINE PROBS2(NN,P,C,BXLEC)
C
C     THIS SUBROUTINE COMPUTES CUMULATIVE POISON
C     PROBABILITIES
C
      INTEGER C
      PP=P*NN
      TERM=1.0
      SUM=TERM
C
      IF(C.EQ.0) GOTO 110
      DO 100 I=1,C
         TERM=TERM*PP/I
         SUM=SUM+TERM
  100 CONTINUE
C
  110 BXLEC=SUM/EXP(PP)
C
      RETURN
      END
```

```
C
C
C
C
      SUBROUTINE ASNN(MC,NS,K,N11,KOPT,C1MIN,C2MIN,N1MIN,N2MIN,ASNMIN)
C
C     THIS SUBROUTINE COMPUTES ASN(PO) VALUES AND ASNMAX
C     VALUES.
C
      DOUBLE PRECISION SUMLOG
      INTEGER C1MIN,C2MIN
      COMMON/BLK1/N2S,N2L
      COMMON/BLK3/N1
      COMMON/BLK4/ALPHA,BETA
      COMMON/BLK5/PO,P1
      COMMON/BLK6/I1,I2
      COMMON/BLK7/SUMLOG(2500)
      COMMON/BLK8/N
      COMMON/BLK11/ASN,ASNMAX
C
C     INITIALIZATION
C     COMPUTE P* (MAXIMUM PROB. FOR ASNMAX)
C
      J=I1+1
      XXX=0.0
      IF(I1.GT.0) XXX=SUMLOG(I1)
      AKONST=10.**(SUMLOG(I2)+SUMLOG(N11-I2-1)-XXX-SUMLOG(N11-I1-1))
      TEMP=1.0/FLOAT(I2-I1)
      AKONST=AKONST**TEMP
      PSTAR=AKONST/(1.0+AKONST)
      IF(K.EQ.1) CALL PROBS1(N11,PSTAR,I2,BXLEC)
      IF(K.EQ.2) CALL PROBS2(N11,PSTAR,I2,BXLEC)
      TEMP=BXLEC
      IF(K.EQ.1) CALL PROBS1(N11,PSTAR,I1,BXLEC)
      IF(K.EQ.2) CALL PROBS2(N11,PSTAR,I1,BXLEC)
      TEMP1=TEMP-BXLEC
      ASNMAX=FLOAT(N11)+N2S*TEMP1
C
      IF(K.EQ.1) CALL PROBS1(N11,PO,I2,BXLEC)
      IF(K.EQ.2) CALL PROBS2(N11,PO,I2,BXLEC)
      TEMP=BXLEC
      IF(K.EQ.1) CALL PROBS1(N11,PO,I1,BXLEC)
      IF(K.EQ.2) CALL PROBS2(N11,PO,I1,BXLEC)
      TEMP2=TEMP-BXLEC
      ASN=FLOAT(N11)+N2S*TEMP2
      IF(ASNMAX.GT.NS.OR.ASN.GT.ASNMIN) GOTO 100
      ASNMIN=ASN
      N1MIN=N11
      N2MIN=N2S
      C1MIN=I1
      C2MIN=I2
C
  100 IF(KOPT.NE.2) GOTO 500
      WRITE(5,110) N11,N2S,TEMP1,ASNMAX,TEMP2,ASN
  110 FORMAT(//10X,2(I3,3X),2(F6.4,3X,F8.4,3X))
C
C
```

END

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