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Selection of Reliability Based Mixed Sampling Plans Indexed Through MAPD and AQL

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Abstract. In this paper the procedure for construction of Reliability based mixed sampling plan (RMSPs) with conditional double sampling plan (CDSP) as attribute plan is given. Further these plans are constructed indexed through MAPD and AQL separately and also compared for their efficiency. Tables are also provided for easy selection of the plan.
Keywords. Operating Characteristic (OC), tangent intercept, maximum allowable percent defective (MAPD), Acceptable quality level (AQL), Acceptance sampling plan.
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Introduction

Reliability based Mixed Sampling Plan is a two stage sampling procedure involving variable inspection in the first stage and attributes inspection in the second stage, if the variables inspection of the first sample does not lead to acceptance. Use of variables on the first sample with attributes on the second sample combines the economy of variables for quick acceptance on the first sample with nonparametric protection of attributes sampling when a questionable lot requires second sample. Reliability based Mixed Sampling Plans are of two types, which are independent and dependent plans. Independent Reliability based Mixed Sampling Plans do not incorporate first sample results in the assessment of the second sample. Dependent Reliability based Mixed Sampling Plans combine the results of the first and second samples in making a decision if a second sample is necessary.

It is the usual practice that while selecting a sampling inspection plan, to fix the OC curve in accordance with the desired degree of discrimination. The sampling plan is in turn fixed through suitably chosen parameters. The entry parameters which is used in the acceptance sampling literature are Acceptable quality level(AQL), Limiting quality Level (LQL), Indifference quality level (IQL) and Maximum Allowable Percent Defective (MAPD). Several authors have provided procedures to design the sampling plans indexed through these parameters for various Acceptance Sampling Plans.

In this paper, Reliability based Mixed Sampling Plan (independent case—single point) with CDSP as attribute plan indexed through MAPD and AQL are constructed separately. The Reliability based mixed sampling plans indexed through MAPD ($p*$) and AQL (p_1) are compared and conclusion along with suggestions for future research are provided in this paper.

Review of Related Literature

Baker and Brobst [1] proposed conditional sampling procedures which are similar to double sampling. These CDSP procedures have OC curves identical to those of comparable double sampling procedures. Conditional double sampling is operationally different from double sampling in that the results of the second sample, if required, are obtained from a related lot and nor from the current lot. According to Baker and Brobst [1], using sample information from related lots results in more attractive OC curves and smaller sample sizes. This reduction in sample size is the principal advantage of these procedures over traditional sampling procedures.

MAPD ($p*$), introduced by Mayer [4] and further studied by Soundarajan [15], Radhakrishnan [5] is the quality level corresponding to the inflection point on the OC curve. The degree of sharpness of inspection about this quality level '$p*$' is measured through 'p_t', the point at which the tangent to the OC curve at the inflection point cuts the proportion defective axis. For designing, a selection procedure for CDSP indexed with MAPD and $R = p_t/p*$ is provided.

The Reliability based Mixed Sampling Plan has been designed under two cases of significant interest. In the first case sample size n_1 is fixed and a point on the OC curve is given. In the second case plans are designed when two points on the OC curve are given. Schilling, E. G. [14] provided the procedure for designing the mixed sampling plans to satisfy the above mentioned conditions. Using this procedure, contributions are made by Devaarul, S. [2] and some more contributions are also made by Radhakrishnan and Sampath Kumar [6, 7, 8, 9, 10], Radhakrishnan and Sekkizhar [11, 12, 13].

Glossary of symbols

$p*$ = Maximum Allowable Percent Defective (MAPD)
p_t = Tangent intercept of the OC curve.
p_1 = The submitted lot quality such that $P_a(p) = 0.95$ (also called AQL).
n_1 = Sample size for variable sampling plan.
n_2 = Sample size for attribute sampling plan.
$n_{1,1}$ = Variable sample size for conditional double sampling plan.
$n_{1,2}$ = First attribute sample size for conditional double sampling plan.
$n_{2,2}$ = Second attribute sample size for conditional double sampling plan.
c_1 = Acceptance number for first stage sample.
c_2 = Acceptance number for second stage sample.
β_j = Probability of acceptance for lot quality p_j.
β'_j = Probability of acceptance assigned to first stage for percent defective p_j.
β''_j = Probability of acceptance assigned to second stage for percent defective p_j.
$h*$ = Relative slope of the OC curve at $p*$.
d_1 = Number of defectives in the first sample.
d_2 = Number of defectives in the second sample.

Operating procedure for RMSPs having CDSP as attribute plan

- Determine the parameters of the mixed plan n_1, $n_{1,2}$, n_{22}, k'', c_1, c_2 and c_3 with reference to OC curve.

- Take a random sample of size n_1 from the lot assumed to be large and put them into life test till time t_0 under given environmental conditions.

- Let m be the total number of specimens that failed during the life test. Let $x_{1,n_1}, x_{2,n_2}, \ldots x_{m,n_1}$ denote the progressively censored life times of a random sample of n_1 test specimens in the first stage.

- If the sample order statistic $\hat{\mu} \geq A' = L + k''\hat{\sigma}$ then accept the process or lot.

- If the sample order statistic $\hat{\mu} < A' = L + k''\hat{\sigma}$ then take another sample of size $n_{1,2}$ from the same lot and put them into life test. Call it as second stage.

- Count the number of specimens (d_1) that failed to confirm the specification limit $L = t_0$, the test duration.

- If the number of defectives $d_1 \leq c_1$, accept the lot.

- If the number of defectives $d_1 > c_3$, reject the lot.
- If $c_1 + 1 < d_1 \leq c_3$, take another sample of size $n_{2,2}$ from the same lot and count the number of defectives d_2.
- If $d_2 \leq c_2$ or $d_1 + d_2 \leq c_3$, accept the lot otherwise reject the lot.

Designing the RMSPs having CDSP as attribute plan indexed through MAPD

The procedure for designing the RMSPs is presented below.

- Assume that the mixed plan is independent.
- Decide the sample size n_1 to be used.
- Calculate the acceptance limit for the variable as

$$A' = L + k''\hat{\sigma}$$
$$k'' = -1 + [((1 - p*)^m)/1 - \beta*]^{1/(m-1)}$$

- Split the probability of acceptance $\beta*$ as $\beta*'$ and $\beta*''$ such that $\beta* = \beta*' + (1 - \beta*')\beta*''$ where $\beta*'$ is the probability of acceptance assigned to the variable sampling plan and $\beta*''$ is the probability of acceptance assigned to the attribute sampling plan. Fix the value of $\beta*'$.
- Determine $\beta*''$ as $\beta*'' = (\beta* - \beta*')/(1 - \beta*')$.
- Determine the appropriate second stage sample of size n_2 and c from

$$P_a(p) = \sum_{r=0}^{c_1} \frac{e^{-n_1 p}(n_{1,2}p)^r}{r!} + \sum_{k=c_1+1}^{c_2} \frac{e^{-n_1 p}(n_{1,2}p)^k}{k!} \sum_{r=0}^{c_2-k} \frac{e^{-n_2 p}(n_{2,2}p)^r}{r!} = \beta*'' \tag{0.1}$$

for $p = p^*$.

Using the above procedure tables can be constructed to facilitate easy selection of RMSPs having CDSP as attribute plan indexed through MAPD.

Construction of tables

The probability of acceptance for RMSPs having CDSP is given in equation (0.1). For $n_{1,2} = n_{2,2} = n$ (say), the inflection point $(p*)$ is obtained by using $d^2P_a(p)/dp^2 = 0$ and $d^3P_a(p)/dp^3 \neq 0$. The relative slope of the OC curve $h*$ is given by $h* = \frac{-p}{p_a(p)} \frac{dp_a(p)}{dp}$ at $p = p*$. The inflection tangent of the OC

Table 1: Various characteristics of RMSPs when $\beta*' = 0.40$

c_1	c_2	c_3	n_2p_1	$\beta*$	$\beta*''$	n_2p*	$h*$	np_t	$R = p_t/p*$
0	1	1	0.272	0.7529	0.5882	0.841	0.7987	1.8940	2.25
0	2	3	0.758	0.6532	0.4220	2.018	1.7706	3.1577	1.56
0	3	4	1.112	0.6311	0.3852	2.661	2.2148	3.8625	1.45
1	3	4	1.159	0.6434	0.4057	2.832	2.1240	4.1653	1.47
1	4	4	1.194	0.6426	0.4043	2.799	2.0695	4.1515	1.48
2	6	6	1.934	0.6225	0.3708	4.062	2.6026	5.6227	1.38
2	6	8	2.601	0.5980	0.3300	5.106	3.3127	6.6473	1.30
3	7	8	2.710	0.6104	0.3507	5.286	3.0435	7.0228	1.33
3	7	11	3.672	0.5814	0.3023	6.779	4.0013	8.4732	1.25
5	9	12	4.320	0.5956	0.3260	7.667	3.7734	9.6989	1.27
5	9	15	5.227	0.5706	0.2843	9.056	4.6957	10.9846	1.21
6	9	15	5.299	0.5795	0.2992	9.212	4.3615	11.3241	1.23
7	11	18	6.566	0.5705	0.2842	10.857	5.0146	13.0221	1.20
7	11	21	7.214	0.5848	0.3080	11.724	5.0447	14.0480	1.20
9	13	23	8.453	0.5579	0.2632	13.540	5.8031	15.8732	1.17
11	15	26	9.880	0.5606	0.2677	15.337	5.9952	17.8952	1.17
15	19	34	13.267	0.5541	0.2568	19.762	6.8171	22.6609	1.15
17	21	36	14.532	0.5643	0.2738	20.931	6.2955	24.2558	1.16

curve cuts the p axis at $p_t = p * +(p * /h*)$. The values of $np*$, $h*$, np_t and $R = p_t/p*$ are calculated for an arbitrary value $\beta*' = 0.40$ (say) using visual basic program and presented in Table 1.

Selection of the plan

Table 1 is used to construct the plans when MAPD ($p*$) and tangent intercept (p_t) are given. For any given values of c_1, c_2, p_t and $p*$, one can find the ratio $R = p_t/p*$. Corresponding to the value of c_1 and c_2 find the value of R in Table 1, which is equal to or just greater than the specified ratio. Corresponding c_3 value is noted. From this c_1, c_2 and c_3 values one can determine the value of $n = np * /p*$.

Table 2 is used to construct the plans when MAPD ($p*$), $m = n, c_1$ and c_2 values are given. For any given values of $p*$, c_1, c_2, c_3 and m, n_1, one can determine n_2 and k''.

Example 1. Given the values of $p* = 0.04$, $p_t = 0.052$, $n_1 = 15$, $m = 5$, $c_1 = 2$, $c_2 = 6$ and $\beta*' = 0.40$. Find the ratio $R = p_t/p* = 1.30$. Using Table 1, corresponding to $c_1 = 2$, $c_2 = 6$ select the value of R equal to or just greater than this ratio. The value of R is 1.30 which is associated with $c_1 = 2$, $c_2 = 6$ and $c_3 = 8$. It is found from Table 2 that $n_2 = 128$ and $k'' = 0.0797$. The RMSPs for specified $p* = 0.04$ is $n_1 = 15$, $m = 5$, $n_{1,2} = 128$, $n_{2,2} = 128$,

Table 2: Second stage sample size and variable factor with $\beta *' = 0.40$ at MAPD.

	R	2.25	1.56	1.45	1.47	1.48	1.38	1.30	1.33	1.25	1.27	1.21	1.23	1.20	1.20	1.17	1.17	1.15	1.16
	c_1	0	0	0	1	1	2	2	3	3	5	5	6	7	7	9	11	15	17
	c_2	1	2	3	3	4	6	6	7	7	9	9	9	11	11	13	15	19	21
$p*$	k''										n_2, c_3								
0.01	0.1200	84,1	201,3	266,4	283,4	280,4	406,6	511,8	529,8	678,11	767,12	906,15	921,15	1086,18	1172,21	1354,23	1534,26	1976,34	2093,36
0.02	0.1079	42,1	101,3	133,4	142,4	140,4	203,6	255,8	264,8	339,11	383,12	453,15	461,15	543,18	586,21	677,23	767,26	988,34	1047,36
0.03	0.0938	28,1	67,3	89,4	94,4	93,4	135,6	170,8	176,8	226,11	256,12	302,15	307,15	362,18	391,21	451,23	511,26	659,34	698,36
0.04	0.0797	21,1	50,3	67,4	71,4	70,4	102,6	128,8	132,8	169,11	192,12	227,15	230,15	271,18	293,21	339,23	383,26	494,34	523,36
0.05	0.0657	16,1	40,3	53,4	57,4	56,4	81,6	102,8	106,8	136,11	153,12	181,15	184,15	217,18	234,21	271,23	307,26	395,34	419,36
0.06	0.0517	14,1	34,3	44,4	47,4	47,4	68,6	85,8	88,8	113,11	128,12	151,15	154,15	181,18	195,21	226,23	256,26	329,34	349,36
0.07	0.0377	12,1	29,3	38,4	40,4	40,4	58,6	73,8	76,8	97,11	110,12	130,15	132,15	155,18	167,21	193,23	219,26	282,34	299,36
0.08	0.0238	11,1	25,3	33,4	35,4	35,4	51,6	64,8	66,8	85,11	96,12	113,15	115,15	136,18	147,21	169,23	192,26	247,34	262,36
0.09	0.0099	9,1	22,3	30,4	31,4	31,4	45,6	57,8	59,8	75,11	85,12	101,15	102,15	121,18	130,21	150,23	170,26	220,34	233,36
0.10	-0.004	8,1	20,3	27,4	28,4	28,4	41,6	51,8	53,8	68,11	77,12	91,15	92,15	109,18	117,21	135,23	153,26	198,34	209,36

$c_1 = 2$, $c_2 = 6$, $c_3 = 8$ and $k'' = 0.0797$.

Explanation: In a sample of $n_1 = 15$ specimens selected from a lot of a Battery manufacturing company, $m = 5$ specimens failed during the life test till time t_0 (specified by the producer/consumer). For a fixed $p* = 0.040$ (40 defectives out of 1000 samples), the value of the parameter k'' is obtained as 0.0797. Let $x_{1,15}, x_{2,15}, \ldots x_{5,15}$ denote the progressively censored life times of a random sample of size 15 test specimens. If the sample order statistic $\hat{\mu} \geq A' = L + 0.0797\hat{\sigma}$ (L = Lower specification limit, $\hat{\sigma}$ = Standard deviation are specified by the producer/consumer) then accept the lot else take another sample of size $n_{1,2}$ (= 128) from the same lot and put them into life test, count the number of defectives d_1. If the number of defectives $d_1 \leq c_1$ (= 2), accept the lot. If the number of defectives $d_1 > c_3$ (= 8) reject the lot. If c_1 (= 2) +1 $< d_1 \leq c_3$ (= 8), take a second sample of size $n_{2,2}$ (= 128) from the remaining lot and find the number of defectives d_2. If $d_2 \leq c_2$ (= 6) or $d_1 + d_2 \leq c_3$ (= 8) accept the lot otherwise reject the lot and inform the management for further action. Hence the RMSP for a specified $p* = 0.04$ is $n_1 = 15$, $m = 5$, $n_{1,2} = 128$, $n_{2,2} = 128$, $c_1 = 2$, $c_2 = 6$, $c_3 = 8$ and $k'' = 0.0797$.

Construction of RMSPs having CDSP as attribute plan indexed through AQL.

The general procedure given earlier is used for constructing the RMSPs having CDSP as attribute plan indexed through AQL (p_1) [for $\beta_1'' = (\beta_1 - \beta_1')/(1-\beta_1')$]. For $n_{1,2} = n_{2,2} = n$ (say), assuming the probability of acceptance of the lot be $\beta_1 = 0.95$, $\beta_1' = 0.40$, $m = 5$, n_2 and k'' values are calculated for different combinations of c_1, c_2, and c_3 using visual basic program and is presented in Table 3.

Selection of the plan

Table 3 is used to construct the plans when AQL (p_1), c_1, c_2, c_3 and m are given. For any given values of p_1, c_1, c_2, c_3 and m, one can determine k'' and n value using $n_2 = n_2 p_1 / p_1$ and $k'' = -1 + [((1 - p*)^m)/1 - \beta_1']^{1/(m-1)}$.

Example 2. Given the values of $p_1 = 0.008$, $n_1 = 15$, $m = 5$, $c_1 = 0$, $c_2 = 2$, $c_3 = 3$, $\beta_1' = 0.40$ and $m = 5$ use Table 3 and find that $n_2 = 95$ with $k'' = 0.1249$. The RMSP for a specified $p_1 = 0.008$ is $n_1 = 15$, $m = 5$, $n_{1,2} = 95$, $n_{2,2} = 95$, $c_1 = 0$, $c_2 = 2$, $c_3 = 3$ and $k'' = 0.1249$.

Explanation. In a sample of $n_1 = 15$ specimens selected from a lot of a Battery manufacturing company, $m = 5$ specimens failed during the life test till time t_0 (specified by the producer/consumer). For a fixed lot quality $p_1 = 0.008$ (8 defectives out of 1000 samples), the value of the parameter k'' is obtained as $k'' = 0.1249$. Let $x_{1,15}, x_{2,15}, \ldots, x_{5,15}$ denote the progressively censored life

Table 3: Second stage sample size and variable factor with $\beta*' = 0.40$ at AQL

	c_1	0	0	0	1	1	2	2	3	3	5	5	6	7	7	9	11	15	17
	c_2	1	2	3	3	4	6	6	7	7	9	9	9	11	11	13	15	19	21
p_1	k''										n_2, c_3								
0.001	0.1348	272,1	758,3	1112,4	1159,4	1194,4	1934,4	2601,6	2710,8	3672,8	4320,11	5227,12	5259,15	6566,18	7214,21	8453,23	9880,26	13267,34	14532,36
0.002	0.1334	1361	379,3	556,4	580,4	597,4	967,4	1301,6	1355,8	1836,8	2160,11	2614,12	2650,15	3283,18	3604,21	4227,23	4940,26	6634,34	7266,36
0.003	0.1320	91,1	252,3	371,4	386,4	398,4	645,4	867,6	903,8	1224,8	1440,11	1742,12	1766,15	2189,18	2405,21	2815,23	3293,26	4422,34	4844,36
0.004	0.1305	68,1	190,3	278,4	290,4	299,4	484,4	650,6	678,8	918,8	1080,11	1307,12	1325,15	1642,18	1804,21	2113,23	2470,26	3317,34	3633,36
0.005	0.1291	54,1	152,3	222,4	232,4	239,4	387,4	520,6	542,8	734,8	864,11	1045,12	1060,5	1313,18	1443,21	1691,23	1976,26	2653,34	2906,36
0.006	0.1277	45,1	126,3	185,4	193,4	199,4	322,4	434,6	452,8	612,8	720,11	871,12	883,15	1094,18	1202,21	1409,23	1647,26	2211,34	2422,36
0.007	0.1263	39,1	108,3	159,4	166,4	171,4	276,4	372,6	387,8	525,8	617,11	747,12	757,15	938,18	1031,21	1208,23	1411,26	1895,34	2076,36
0.008	0.1249	34,1	95,3	135,4	145,4	149,4	242,4	325,6	339,8	459,8	540,11	653,12	662,15	821,18	902,21	1097,23	1235,26	1658,34	1817,36
0.009	0.1235	30,1	84,3	124,4	129,4	131,4	215,4	289,6	301,8	408,8	480,11	581,12	589,15	730,18	802,21	939,23	1198,26	1474,34	1685,36
0.010	0.1220	27,1	76,3	111,4	116,4	119,4	193,4	260,6	271,8	367,8	432,11	523,12	530,15	657,18	721,21	845,23	98826	1327,34	1453,36

Table 4: Comparison of plans.

Given values				Through MAPD		Through AQL	
c_1	c_2	$p*$	p_t	n_2	c_3	n_2	c_3
0	3	0.048	0.070	55	4	64	4
2	6	0.069	0.090	74	8	82	8
5	9	0.400	0.500	23	15	25	15
7	11	0.500	0.600	22	18	24	18
9	13	0.110	0.129	123	23	131	23
15	19	0.165	0.190	120	34	126	34

times of a random sample of size 15 test specimens. If the sample order statistic $\hat{\mu} \geq A' = L + 0.1249\hat{\sigma}$ (L = Lower specification limit, $\hat{\sigma}$ = Standard deviation are specified by the producer/consumer) then accept the lot else take another sample of size $n_{1,2}$ (= 95) from the same lot and put them into life test, count the number of defectives d_1. If the number of defectives $d_1 \leq c_1$ (= 0), accept the lot. If the number of defectives $d_1 > c_3$ (= 3) reject the lot. If c_1 (= 0) $+1 < d_1 \leq c_3$ (= 3), take a second sample of size $n_{2,2} = 95$ from the remaining lot and find the number of defectives d_2. If $d_2 \leq c_2$ (= 2) or $d_1 + d_2 \leq c_3$ (= 3) accept the lot otherwise reject the lot and inform the management for further action. Hence the RMSP for a specified $p_1 = 0.008$ is $n_1 = 15$, $m = 5$, $n_{1,2} = 95$, $n_{2,2} = 95$, $c_1 = 0$, $c_2 = 2$, $c_3 = 3$, and $k'' = 0.1249$.

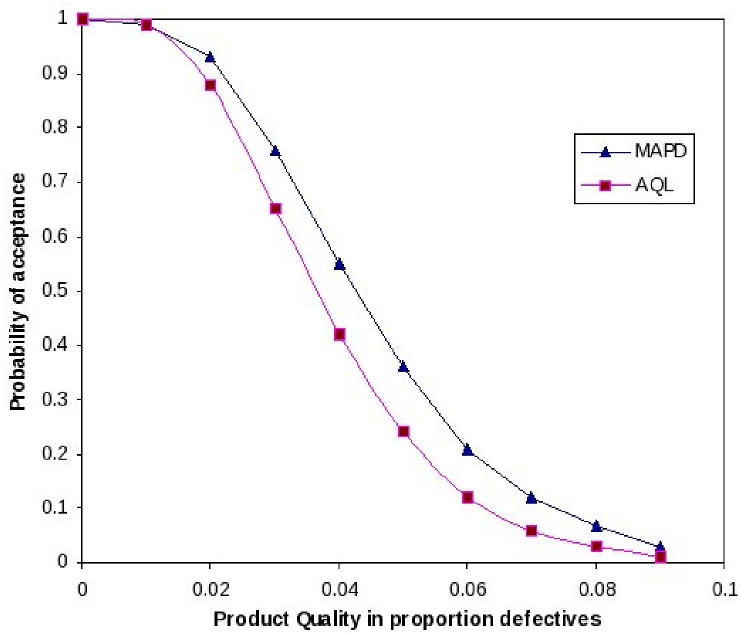
Comparison of CDSP indexed through MAPD and AQL.

In this section CDSP indexed through MAPD is compared with CDSP indexed through AQL. For the given values of $p*$ and p_t, one can find the values of c_1, c_2, c_3 and n_2 indexed through MAPD with $\beta*' = 0.40$ from Table 1. For various combinations of $p*$ and p_t, the values of n, c_1, c_2, c_3 (indexed through MAPD) and n, c_1, c_2, c_3 (indexed through AQL) are calculated and presented in Table 4:

Construction of OC curve

The OC curves of RMSPs with CDSP as attribute plan are constructed for the plans $n_{1,1} = 55$, $n_{1,2} = 55$, $c_1 = 0$, $c_2 = 3$, $c_3 = 4$ (indexed through MAPD) and $n_{1,1} = 64$, $n_{1,2} = 64$, $c_1 = 0$, $c_2 = 3$, $c_3 = 4$ (indexed through AQL) are presented in Figure 1.

Figure 1: OC curve



Conclusion

It is concluded from the study that the second stage sample size required for RMSPs with CDSP as attribute plan indexed through MAPD is less than that of the second stage sample size of the CDSP indexed through AQL with more probability of acceptance and less inspection cost. These plans offer effectiveness and flexibility to the floor engineers and help them to decide their sampling plans on the floor itself and can take quick decisions to make the system very fast, effective and friendly. Different plans can also be constructed indexed through MAAOQ, LQL and IQL to compare their efficiencies. To make the system more effective and user friendly one can change the stage probabilities and proceed with the RMSPs.

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