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Design of multiple deferred state sampling inspection plan for variables

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Abstract
The statistical product control, also termed as, acceptance sampling, extensively used in enterprises to reach a decision on ruling of lots of manufactured products, is a definite plan that states the sampling rules to be used and the standards for acceptance or dismissal of lots submitted for inspection. In acceptance sampling, the largely used practice to minimize the testing time and cost of inspection of manufactured units is the variable sampling inspection plan, in which the sentencing of a lot of individual items is based on metrical data. One of the special purpose sampling plans, multiple deferred state sampling plan for attributes reviews the quality of current lot as well as forthcoming lots for settlement of a lot. This paper proposes a technique for designing a multiple deferred state sampling plan for variables with the quality characteristics of product following normal distribution. The optimized parameters of the proposed plan are assessed by utilizing two points on the operating characteristic (OC) curve for specific requirement to ensure upon the producer and consumer conservation, when the standard deviation is known and unknown.

Keywords: Acceptance sampling plans, variable sampling plans, multiple deferred state sampling plan, normal distribution

1. Introduction

At present circumstances, the quality of manufactured materials or services plays significant role in attracting the attention of a customer. The quality of finished goods are ensured either by a 100% inspection or by a sampling inspection. When the items/units in submitted lots are destructive in nature or inspection procedure is costly or time consuming, a sampling inspection is typically employed. The decision on acceptance or non -acceptance of submitted lots are made, usually based on relevant sampling inspection procedures called sampling plans. In sampling inspection plans either attribute or variable quality characteristics can be tested.

In sampling inspection by variables, samples are drawn from the lots submitted for inspection and the measurement on requisite quality characteristics of products are recorded. These measurements are compared with pre-fixed specification limits, to get to a decision on acceptance, rejection, or resampling. The sampling inspection plans by variables are more efficient, since they provide more information regarding sampled units and moreover the same operating characteristic (OC) curve as that of attribute sampling plans can be obtained with a comparatively smaller sample sizes (Montgomery, Bowker and Goode) [6, 1]. In literature, the variable sampling inspection plans has been designed by many researchers. A few of them are Schilling [10], Lieberman and Resnikoff [11], Owen [4, 5], Hamaker [13], Bravo and Wetherill [17], Baillie [7].

The conditional sampling inspection plans is one of the special purpose sampling plans, which utilizes the knowledge from the neighbouring lots together with the present lots to get to a decision on accepting or discarding the lot. Dependent state and chain sampling plans uses the information from past lots along with the ongoing lots to attain a decision, whereas the deferred state sampling inspection plans uses the knowledge from upcoming lots as well as the current lot for judgement. Wortham and Baker in 1976 [3] extended the idea of fixed deferred state sampling plan to a multiple deferred state sampling plan for attributes.

Wortham and Baker proposed the multiple deferred state sampling plans which are applicable when the lots are submitted serially in the order of their production, the sample size from lots are assumed to be fixed and the inspection is by attributes with fraction defective from a binomial distribution. Soundararajan and Vijayaraghavan [25] Govindaraju and Subramani [14], developed multiple deferred state sampling plans for attributes with fixed parameters, following the operating procedures and characteristics developed by Wortham and Baker. Further, the plan was investigated by Vaerst [18] in 1982 to make it on a par with the chain sampling plan (ChSP-1). Vaerst has modified the operating procedures and characteristic function of the existing multiple deferred state sampling plan and the research works that has been carried out regarding in the literature are: Soundararajan and Vijayaraghavan [25], Subramani and Haridoss [15], Balamurali and Kalyanasundaram [19], Senthilkumar, Lokanayaki and Esha Raffie [9], Balamurali, Jeyadurga and Usha [21, 22, 23], Latha and Palanisamy [16], Srinivasa Rao, Rosaiah and Ramesh Naidu [12]. While examining the literature, no attempts have been made in designing a multiple deferred state sampling inspection plans for variables using normal distribution under the assumption of Wortham and Baker.

This paper proposes the designing of a multiple deferred state sampling (MDSS) inspection plan for variables, whose quality characteristics following normal distribution, with the operating procedures and characteristics according as Wortham and Baker. The procedures for obtaining the proposed plan parameters at specific risks are also developed. A comparative study has been carried out.

2. Variable Multiple Deferred State Sampling (MDSS) Plan

2.1 Basic Assumptions for Implementation of Proposed Plan

The basic assumptions for execution of proposed plan are as follows:

1. The production is steady so that the results of current lots and future lots are highly indicative of a continuing process.
2. Lots are submitted substantially in the order of production.
3. The operating characteristics (OC) curves are determined for inspection by variables with stable quality between lots.
4. The characteristics under consideration follows normal distribution.

2.2 Operating Procedures

Assume that the quality characteristics under study be normally distributed with mean μ and unknown standard deviation σ, and with an upper specification limit, U, specified.

1. The proposed variable MDSS plan executes as follows:
2. From each lot put forward for inspection, draw a random sample of n units, $(x_1, x_2, \ldots, x_n)$ say.
   Evaluate $= \frac{U-\bar{x}}{S}$, where $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ and $S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$, S^2 is an unbiased estimate of σ^2.
3. The current lot is accepted for $v \geq k_a$, the current lot is discarded for $v < k_r$. The decision on current lot is delayed up to subsequent m lots for $k_r \leq v < k_a$ and the lot is accepted if all the m lots are accepted. Reject the lot on non-acceptance of any of the m lots.

Thus the proposed variable MDSS inspection plan is described by four parameters, namely, n – the sample size; m – the number of upcoming lots for conditional acceptance; k_a – the unconditional acceptance constant; k_r– the conditional acceptance constant.

The optimum parametric values of the proposed plan are achieved by selecting two points on operating characteristic curve, namely, $(AQL, 1-\alpha)$ and (LQL, β) employing a search procedure; where $AQL\ (or\ p1)$ is the acceptable quality level, and $LQL\ (or\ p2)$ is the limiting quality level respectively associated with the producer's risk, α and the consumer's risk, β.

Whenever the lower specification limit, L is stated the proposed variable MDS plan operates as same as above, apart from step 2. The corresponding statistic in step 2 will be changed as

$$v = \frac{\bar{x}-L}{S}$$

2.3 Operating Characteristic function

The prominent aid for judging the performance of a variable sampling plan is operating characteristic (OC) function, a function of incoming lot quality, p. It gives the lot acceptance probability $P_a(p)$. The OC curve is drawn by plotting $P_a(p)$ against p.

For a preassigned upper specification limit, U the proportion non-conforming is expressed as,

$$p = P\{X > U|\mu\} = 1 - \Phi\left(\frac{U-\mu}{S}\right) \quad (1)$$

Where $\Phi(.)$ is the cumulative distribution function of standard normal random variable. Thus the fraction non-conforming p and unknown mean μ are related through (1). The operating characteristic function of unknown sigma variable MDSS plan is attained through asymptotic normality of $\bar{x} \pm k_a S$.

According to Duncan (1986) [2], $\bar{x} \pm k_a S$ is asymptotically normally distributed with mean

$\mu \pm k_a\sigma$ and variance $\frac{\sigma^2}{n}\left(1 + \frac{{k_a}^2}{2}\right)$

i.e., $\bar{x} + k_a S \sim N\left(\mu + k_a\sigma, \frac{\sigma^2}{n}\left(1 + \frac{{k_a}^2}{2}\right)\right)$

Following Wortham and Baker (1976), the operating characteristic function of the proposed variable MDSS inspection plan is as follows:

$$P_a(p) = P\{v \geq k_a|p\} + P\{k_r \leq v < k_a|p\}[P_a(p)]^m \quad (2)$$

Where $P\{v \geq k_a|p\}$ is the unconditional probability of accepting a lot based on current sample and $P\{k_r \leq v < k_a|p\}$ is the conditional probability that the decision on current lot will be deferred until the decision of m future lots.

The probabilities in RHS of (2) can be rewritten as

$$P_a(p) = \Phi(w_1) + [\Phi(w_2) - \Phi(w_1)][P_a(p)]^m \quad (3)$$

$$\text{Where, } w_1 = \left(\frac{U-\mu}{\sigma} - k_a\right)\sqrt{\frac{n}{1+\frac{{k_a}^2}{2}}} = (Z_p - k_a)\sqrt{\frac{n}{1+\frac{{k_a}^2}{2}}} \quad (4)$$

and $w_2 = \left(\frac{U-\mu}{\sigma} - k_r\right)\sqrt{\frac{n}{1+\frac{k_r^2}{2}}} = \left(Z_p - k_r\right)\sqrt{\frac{n}{1+\frac{k_r^2}{2}}}$ (5)

2.4 Designing of Variable MDSS Unknown Sigma Plan

For specific AQL and LQL, the proposed plan parameters are enumerated by ensuring requisite producer and consumer conservation. The plan variables should simultaneously satisfy the following conditions.

$$P_a(p_1) = \Phi(w_{11}) + [\Phi(w_{21}) - \Phi(w_{11})][P_a(p_1)]^m \geq 1-\alpha \quad (6)$$

and

$$P_a(p_2) = \Phi(w_{12}) + [\Phi(w_{22}) - \Phi(w_{12})][P_a(p_2)]^m \leq \beta \quad (7)$$

Where,
w_{11} = the value of w_1 at p = AQL (or p_1)
w_{21} = the value of w_2 at p = AQL
w_{12} = the value of w_1 at p = LQL (or p_2)
w_{22} = the value of w_2 at p = LQL

On solving equations (6) and (7) together, there may exists numerous solutions. Hence we would work out the plan parameters so as to minimize the average sample number (ASN). Consequently the problem for determining the proposed plan variables such as (n, m, k_a, k_r) has been set up as follows.
For pre-fixed values of m, $(AQL, 1-\alpha)$ and (LQL, β) the problem is to
Minimize $ASN = n$
Such that

$$P_a(p_1) \geq 1-\alpha \quad (8)$$

$$P_a(p_2) \leq \beta$$

$$n \geq 1,\ k_a > k_r > 0$$

Where $P_a(p_1)$ and $P_a(p_2)$ are respectively the probability of acceptance of lot at AQL and LQL and is given in equations (6) and (7) respectively.

3. Variable MDSS Plan for Known Standard Deviation

3.1 Operating Procedure

Suppose that the quality characteristic of interest be normally distributed with mean μ and standard deviation σ. Let U be the specific upper specification limit.
The proposed variable MDS sampling inspection plan performs as follows:

1. Take a random sample of n′ items, say ($X_1, X_2 \ldots X_{n'}$), from each lot set forth for inspection.
2. Evaluate $v = \frac{U-\bar{x}}{\sigma}$, where $\bar{x} = \frac{1}{n'}\sum_{i=1}^{n'} x_i$
3. If $v \geq k_a'$, the current lot is accepted, if $v < k_r'$, the current lot is not accepted. If $k_r' \leq v < k_r'$, the decision on the current lot is deferred until observing subsequent m' lots and the lot is accepted if the subsequent m' lots are all accepted. Reject the lot on non-acceptance of any of the m' lots.

Thus the proposed variable MDSS inspection plan is defined by four parameters(n', m', k_a', k_r'). A two point approach on OC curve, employing a search procedure is utilized to get the optimum plan parameters.

3.2 Operating Characteristic Function

For a specific upper specification limit U, the proportion non - conforming is expressed as,

$$p = P\{X > U|\mu\} = 1 - \Phi\left(\frac{U-\mu}{\sigma}\right) \quad (9)$$

Where Φ(.) is the cumulative distribution function of standard normal random variable.
The OC function of proposed variable MDSS plan for known standard deviation is given by:

$$P_a(p) = P\{v \geq k_a'|p\} + P\{k_r' \leq v < k_a'|p\}[P_a(p)]^{m'} \quad (10)$$

The lot acceptance probability can be rewritten as

$$P_a(p) = \Phi(y_1) + [\Phi(y_2) - \Phi(y_1)][P_a(p)]^{m'} \quad (11)$$

Where $y_1 = (Z_p - k_a')\sqrt{n'}$ (12)

$$y_2 = (Z_p - k_r')\sqrt{n'} \quad (13)$$

and $Z_p = \frac{U-\mu}{\sigma}$

3.3 Designing of Known Sigma Variable MDSS Plan

For given AQL and LQL values the plan parameters are enumerated by guaranteeing requisite conservation for producer and consumer. That is the required parameters shall simultaneously satisfy

$$P_a(p_1) = \Phi(y_{11}) + [\Phi(y_{21}) - \Phi(y_{11})][P_a(p_1)]^{m'} \geq 1-\alpha \quad (14)$$

And

$$P_a(p_2) = \Phi(y_{12}) + [\Phi(y_{22}) - \Phi(y_{12})][P_a(p_2)]^{m'} \leq \beta \quad (15)$$

Where,
y_{11} = the value of y_1 at p = AQL (or p_1), y_{21} = the value of y_2 at p = AQL
y_{12} = the value of y_1 at p = LQL (or p_2), y_{22} = the value of y_2 at p = LQL

As in the case of unknown sigma plan, the plan variables for this case are obtained as follows.
For pre-assigned values of m', $(AQL, 1-\alpha)$ and (LQL, β)
Minimize $ASN = n'$
Subject to

$$P_a(p_1) \geq 1-\alpha \quad (16)$$

$$P_a(p_2) \leq \beta$$

$$n' \geq 1,\ k_a' > k_r' > 0$$

Where $P_a(p_1)$ and $P_a(p_2)$ are respectively the probability of acceptance of lot at AQL and LQL and is given in equations (14) and (15) respectively.
Tables are constructed for unknown and known sigma variable MDSS plan at m (m') =1, 2 and 3 indexed by various AQL and LQL values with associated risks, α=0.05 and β=0.10
In particular, when $m = 0$ $(or\ m' = 0)$ the proposed variable MDSS plan becomes usual variable sampling plan with parameters n and k_r (or n' and k_r'). Also when $k_a =$

k_r ($or\ k'_a = k'_r$), the proposed plan reduces to conventional variable single sampling plan with parameters n and k_a (or n' and k'_a).

4. Comparative Study

This part investigates the efficiency of recommended MDSS plans for variables. The proposed plan is compared to variable single sampling plan (SSP) and double sampling plan for variables (DSP) of Sommers (1981) [8] and multiple dependent state (MDS) sampling plan for variables developed by Balamurali *et al*. [20] and is perceived to be more efficient concerning smaller sample sizes together with producer and consumer conservation. The acceptance sampling plans are said to be analogous if they provide nearly alike OC curves. Hence OC curves has been drawn for the referred variable sampling plans. Besides tables are prepared and are presented for easy comparison of the average sample numbers.

In particular, for specified values of $AQL = 1\%, \alpha = 5\%, LQL = 4\%\ and\ \beta = 10\%$, one can notice that

$n' = 5, k_a{}' = 2.71, k_r{}' = 1.29$; when $m' = 1$

$n' = 7, k_a{}' = 2.27, k_r{}' = 1.41$; when $m' = 2$

$n' = 9, k_a{}' = 2.19, k_r{}' = 1.34$; when $m' = 3$

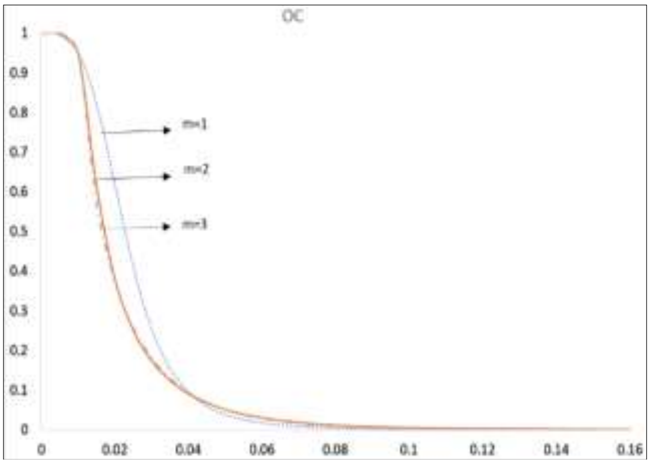

Fig 1: OC curve for variable MDSS plan at m′=1, m′=2, m′=3.

The performance of the proposed MDS sampling variable plans are measured by drawing the OC curves for the plan at different m' values. It can be observed that the MDS plan having large value of m' appears to be nearer to ideal OC curve. The value of m' is chosen by considering sample size and its OC curve.

Now one can realize that for the same $(AQL, 1-\alpha)$ and (LQL, β), the optimum parameters of single sampling plan for variables (seen in Sommers,1981) and variable multiple dependent state sampling plan (MDS)(from Balamurali. *et al*., 2007) are:

$n' = 26, k_a{}' = 2$

$n' = 16, k_a{}' = 2.12, k_r{}' = 1.72$; when $m' = 1$;

In this instance, it is noticed that the proposed variable MDSS plan ($n' = 5,\ k_a{}' = 2.71, k_r{}' = 1.29$; when $m' = 1$) is having comparably smaller sample size than single variable sampling plan and multiple dependent state variable sampling plan.

Also the OC curves for variable MDSS plan (at $m' = 1$), single sampling plan for variables (SSP) and multiple dependent state (MDS) sampling plans are drawn for comparison.

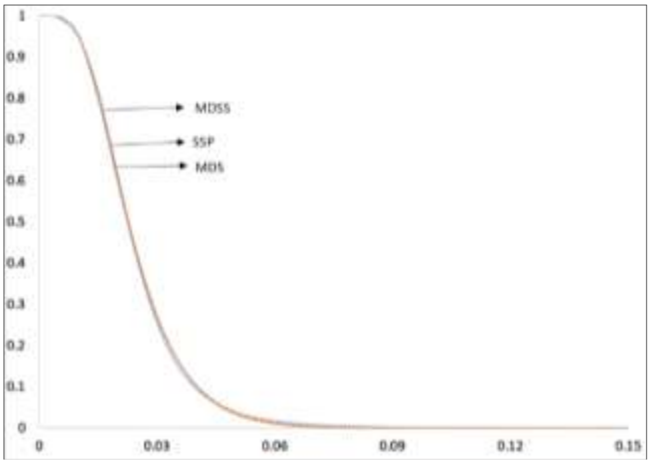

Fig 2: OC curve for variable MDSS plan (m′=1), variable SSP, and variable MDS plan (m′=1).

It is clear from the OC curve that the proposed MDSS plan for variables provides almost same protection to producer and consumer as that of variable single sampling plan and multiple dependent state sampling plan for variables, with a comparatively small sample size.

Thereafter, we compare the ASN (Average Sample Number) of the proposed variable MDSS plan with variable single sampling plan (SSP), variable double sampling plan (DSP), and variable multiple dependent state (MDS) sampling plan. Generally a sampling plan having smaller ASN would be preferred. Table:1 have been constructed for comparing the ASN of the proposed variable MDSS plan when $m' = 1$ (or m=1), variable SSP and DSP (Sommers, 1981) and variable MDS plan (Balamurali. *Et al*., 2007). It is observed that variable MDSS plan is efficient than SSP, DSP and MDS sampling plans for variables concerning ASN.

Table 1: ASN of single, double, multiple dependent state and multiple deferred state sampling plans for variables

AQL	LQL	Average Sample Number							
		Known Sigma				Unknown Sigma			
		Single	Double	Multiple Dependent	Multiple Deferred	Single	Double	Multiple Dependent	Multiple Deferred
0.01	0.04	26	21.4	16	5	78	62.5	51	16
0.015	0.06	23	18.6	14	4	61	48.3	40	12
0.02	0.08	21	16.9	13	3	50	39.6	33	9
0.03	0.12	18	14.2	11	4	37	29.6	24	9
0.05	0.20	14	10.9	9	4	23	18.6	16	7

5. An Illustrative Example

The application of proposed Variable MDSS plan is illustrated using the following example. Suppose that the manufacturer demands the probability of accepting the product should be exceeding 95%, if the fraction non-conforming is less than 0.01. On the contrary, the consumer requisite the probability of accepting the product should not be more than 90%, if the fraction non-conforming is larger than 0.04. Hence for this case, when sigma is unknown and at m=2, the optimum plan parameters can be found from the table to be (n, k_a, k_r) = (22, 2.31, 1.48). Now the proposed sampling plan operates as follows:

Lot A: A sample of 22 units is taken from lot A. Obtain the sample mean, $\bar{x}$ and $S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$. For given upper specification limit, U, evaluate the statistic $v = \frac{U-\bar{x}}{S}$

If $v \geq 2.31$, accept lot A, if v <1.48, reject lot A. If $1.48 \leq v < 2.31$, defer the decision on acceptance of lot A until the consecutive 2 future lots, say, lot B and lot C are both accepted. Otherwise reject the lot A.

6. Conclusion

A Multiple Deferred State Sampling (MDSS) Plan for Variables is suggested in this study for disposition of lots of products whose quality characteristics follows normal distribution. The average sample number of the proposed MDSS plan is relatively smaller than variable single sampling plan, double variable sampling plan and variable multiple dependent state sampling plan. The proposed plan provides same producer and consumer protection as that of referred plans, along with a smaller sample size.

Table 2: Variable Multiple Deferred State Sampling Plan for $m' = 1 (or\ m = 1), \alpha = 0.05, \beta = 0.10$ indexed by AQL and LQL

AQL	LQL	Known Sigma			Unknown Sigma		
		n′	Ka′	Kr′	n	Ka	Kr
0.010	0.020	10	3.02	1.32	41	3.10	1.60
	0.040	5	2.71	1.29	16	2.91	1.46
	0.060	3	2.76	1.02	9	3.06	1.27
0.015	0.030	10	2.80	1.21	31	3.10	1.38
	0.045	6	2.65	1.15	18	2.89	1.33
	0.060	4	2.69	0.96	12	2.90	1.23
0.020	0.040	13	2.43	1.33	39	2.51	1.45
	0.060	6	2.47	1.07	14	2.99	1.13
	0.080	3	2.82	0.56	9	3.11	1.00
	0.100	3	2.50	0.74	8	2.75	1.03
0.030	0.060	14	2.15	1.24	32	2.32	1.27
	0.080	7	2.23	0.99	16	2.48	1.09
	0.010	4	2.44	0.65	10	2.75	0.92
0.040	0.080	8	2.38	0.73	22	2.44	1.02
	0.100	6	2.25	0.72	14	2.48	0.92
	0.120	6	1.99	0.86	11	2.36	0.89
0.050	0.100	7	2.34	0.54	17	2.54	0.83
	0.120	6	2.15	0.61	13	2.39	0.81
	0.140	5	2.06	0.59	10	2.33	0.76

Table 3: Variable Multiple Deferred State Sampling Plan for m′=2 (or m=2), α=0.05, β=0.10 indexed by AQL and LQL

AQL	LQL	Known Sigma			Unknown Sigma		
		n′	Ka′	Kr′	n	Ka	Kr
0.010	0.020	25	2.32	1.77	87	2.33	1.77
	0.040	7	2.27	1.41	22	2.31	1.48
	0.060	4	2.22	1.17	11	2.33	1.14
0.020	0.040	19	2.06	1.24	61	2.06	1.41
	0.060	7	2.06	0.84	23	2.06	1.18
	0.100	4	1.97	0.86	9	2.07	0.72
0.040	0.080	23	1.69	1.29	42	1.74	1.20
	0.100	8	1.76	0.51	20	1.76	0.84
	0.120	6	1.73	0.65	15	1.73	0.92

Table 4: Variable Multiple Deferred State Sampling Plan for m′=3 (or m=3), α=0.05, β=0.10 indexed by AQL and LQL

AQL	LQL	Known Sigma			Unknown Sigma		
		n′	Ka′	Kr′	n	Ka	Kr
0.010	0.020	39	2.26	1.86	145	2.26	1.93
	0.040	9	2.19	1.34	33	2.18	1.63
	0.060	5	2.14	1.04	16	2.15	1.17
0.020	0.040	43	1.95	1.73	101	1.97	1.67
	0.060	12	1.94	1.12	33	1.94	1.13
	0.080	7	1.90	0.92	19	1.90	1.14
	0.100	5	1.88	0.49	14	1.87	1.08
0.040	0.080	25	1.67	1.14	57	1.67	1.19
	0.100	15	1.62	1.12	32	1.64	1.09
	0.120	9	1.62	0.65	20	1.62	0.55

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