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Selection of Three-Class Attributes Single Sampling Plan Indexed Through Maximum Allowable Average Outgoing Quality

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Abstract

The traditional 2-class sampling plans are used to classify the lot of items as acceptable or non-acceptable by considering only the number of non-conformities found in the sample. These plans do not provide any consideration for marginal defective items. By considering the near miss item as marginal, the 3-class sampling plans are used to take a decision to accept or reject a lot based on not only the number of non-conformities; but also on the number of marginal items. This paper presents the procedure for constructing the Single Sampling Plan for three attribute classes using Maximum Allowable Average Outgoing Quality (MAAOQ) as quality standard. A table is also constructed for easy selection of these plans. The selection of the plan for the given MAAOQ is explained with an example.

Keywords and Phrases: Marginal Quality, Maximum Allowable Average Outgoing Quality, Operating Characteristic, Single Sampling Plan, Three-Class Attributes Plan.

AMS Classification: Primary 62P30; Secondary 62P30.

1 Introduction

In Statistical Quality Control (SQC), the two major techniques employed to control and monitor the quality of a product are control charts and acceptance sampling. The control chart technique is used to maintain the quality by controlling the production process itself. The sole purpose of the acceptance sampling is to develop acceptance sampling plans (specifying n & c) to accept or reject a lot before reaching the consumer. A sampling plan usually accepts good lots and rarely accepts bad lots. Good and bad are defined by the management in terms of fractions of the lot, which are defective and are specified as Acceptable Quality Level (AQL) and Lot Tolerance Proportion defective (LTPD).

In acceptance sampling literature, it is the usual practice to design the sampling plans indexed by any one or two of the input parameter(s) such as AQL, LTPD, IQL (indifference quality level), AOQL (Average out going quality limit), MAPD (maximum allowable percent defective), MAAOQ (Maximum Allowable Average Outgoing Quality) and so on. Many papers have been published to design the sampling plans indexed by these parameters. Such plans are useful for the manufacturer while specifying the quality of the product to the customer by means of a sampling plan and also useful for the customer to verify the quality with the aid of these plans.

Generally, the acceptance sampling has been carried out using either 2-class attributes plans or variables plans. These plans classify a lot of items as acceptable or non-acceptable, the proportion of the non-acceptable being called the proportion defective. These plans attempt solely to control the proportion defective accepted. But these plans provide no information on the proportion of items in the area around the quality limit, that is, they do not distinguish between a near miss item and an extremely bad one. Such information could be very useful in resolving contested decisions. For example, in food industry, among the variety of sampling plans available for the evaluation of bacterial counts or concentrations of microorganisms, the 3-class attributive sampling plan has widely gained acceptance because of its simple application and its robust functionality. The 2-class plans are used where no living cells of a specific organism or where no piece of a specific type of extraneous material is tolerated in foods, where as, the 3-class plans are used where some cells of the organism in question, or, where the presence of certain amount of extraneous material are tolerated. Standards and guidelines can be applied only when the appropriate method of analysis (or equivalent) is used. A microbiological sampling plan (criteria) is a set of parameters used to determine whether a specific lot of food is acceptable or not. These parameters are (a) the confidence level that an unacceptable lot will be detected, (b) the number of sample units to be taken and (c) the number of positive sample units that are allowed before rejecting the lot.

A positive sample (bad) unit is nothing but a sampling unit that has concentrations of microorganisms per g/mL more than M (unacceptable concentrations of microorganisms per g or mL). A negative sample (good) unit is a sampling unit that has concentrations of microorganisms per g/mL less than m (acceptable concentrations of microorganisms per g or mL). A marginal sample unit is nothing but a sampling unit that has concentrations of microorganisms per g/mL in between m and M, where as, in a 2-class plan, a positive sample (bad) unit is nothing but a sampling unit that has concentrations of microorganisms per g/mL more than m. A negative sample (good) unit is a sampling unit that has concentrations of microorganisms per g/mL less than m.

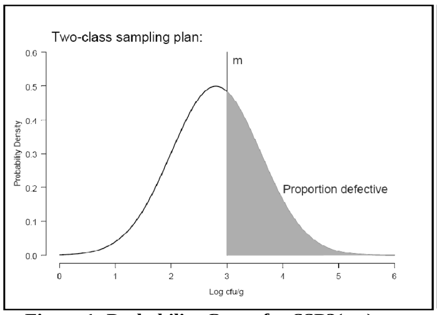

Figure 1: Probability Curve for SSP2(n,c)

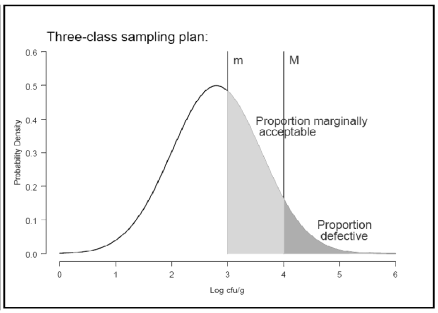

Figure 2: Probability Curve for SSP3(n,c_1,c_2)

In other words, in a 2-class plan, "m" separates sample units of acceptable and defective quality; in a 3-class plan, "m" separates sample units of acceptable quality from those of marginally acceptable quality. The ''m" values are based on levels achievable under Good Manufacturing Process (GMP). "M" separates sample units of marginally acceptable quality from those of defective quality. A value determined for any sample unit of a sample that is greater than "M" renders the pertaining lot unacceptable and these concepts are explained in Figure 1 and Figure 2.

The probability of lot rejection due to a single sample result above M increases with increasing lot heterogeneity and/or with decreasing distance between these limits m and M. Especially for investigations on nonpathogenic microorganisms it is questionable whether a lot still meeting GMP conditions should be rejected solely because a single sample result lies above M. Bray et al (1973) introduced a special type of plan which considers a near miss item as marginal and is called 3-class attributes plan. This procedure classifies three categories of quality namely good, marginal and bad. The lot quality is defined by the two proportions namely proportion of marginal and proportion of bad items. By considering this aspect in mind, an attempt is made in this paper to construct the 3-class attributive single sampling plans indexed through MAAOQ.

2 Glossary of Symbols and Terms used

The symbols used in the sampling plans and their definitions are as follows:

- *Lot* : A batch or production unit which may be identified by the same code. When there is no code identification, a lot may be considered as that (a) the quantity of product produced under essentially the same conditions, (b) at the same establishment and representing no more than one day's production; or (c) the quantity of the same variety of product from one and the same manufacturer available for sampling at a fixed location.

- n : Sample size; the number of sample units selected at random from a lot.
- m : The numerical value of acceptable concentrations of microorganisms or amounts of extraneous material, usually per g or mL.
- M : Only in a 3-class plan, the numerical value of unacceptable concentrations of microorganisms or amounts of extraneous material, usually per g or mL, that indicate a (potential) health or injury hazard, imminent spoilage or gross insanitation.
- c : The maximum allowable number of unacceptable sample units which is the acceptance number of a 2-class plan. When this number is exceeded, the lot becomes unacceptable.
- p_g : Proportion of good quality units having concentrations of organism less than m in a sample of size n.
- p_M : Proportion of marginal quality units having concentrations of organism between m and M in a sample of size n.
- p_b : Proportion of bad quality units having concentrations of organism exceeds M in a sample of size n.
- d_1 : Total number of marginal and bad units found in the first sample of size n.
- d_2 : Number of bad units found in the first sample of size n.
- c_1 : Acceptance number for the marginal and bad units; the maximum allowable number of marginal and unacceptable sample units in a 3-class plan. When this number is exceeded, the lot becomes unacceptable.
- c_2 : Acceptance number for the bad units; the maximum allowable number of unacceptable sample in a 3-class plan. When this number is exceeded, the lot becomes unacceptable.
- $p*$: Maximum Allowable Percent Defective (MAPD); the sum of proportion of marginal units and proportion of bad units at the inflection point of the OC Surface.
- Pa(p_M,p_b) : Probability of acceptance for the given quality level (p_M, p_b)
- SSP3(n,c_1,c_2) : Single sampling plan for three attribute classes with parameters n,c_1 and c_2.

3 Review of Literature

Clements (1979) proved that 3-class attributes plans are more efficient than the conventional two-class attribute plans. Newcombe and Allen (1988) developed a 3-class procedure for acceptance sampling by variables. Ravi Sankar (1989) further studied these 3-class attribute plans. Suresh and Ravi Sankar (1990) developed procedure for Double Sampling Plan for three attribute classes and Suresh et al. (1990) developed procedure for Link Sampling Plan for three attribute classes. Gowri Shankar et al. (1991) developed chain-sampling plan for three attribute classes. International Commission on Microbiological Specifications for Foods (ICMSF) (1986) provides the concept of these 3-class attributes sampling plans and their applications. Hildebrandt. G. et al. (1995) discussed the use of 3-class plans in microbiological quality control. Introducing a limit for the additional risk of rejection of an indifference lot with acceptable heterogeneity when the 3-class sampling plan is applied, a criterion for choosing the distance between m and M is developed by Dahms and Hildebrandt (1998). For controlling level of hazard in food industry Government of Canada (1999) in its Extraneous Matter Overview specifies the standards and guidelines in terms of 2-class plans or 3-class plans depending on the degree of hazard involved.

Whiting et al. (2006) suggested the method for determining the microbiological criteria for lot rejection from the performance objective or food safety objective. Vargas et al. (2006) studied the establishment of maximum limits for Ochratoxin-A (OTA) in coffee. Importing countries requires that coffee-producing countries must develop scientifically based sampling plans to assess OTA contents in lots of green coffee before coffee enters the market thus reducing consumer exposure to OTA, minimizing the number of lots rejected, and reducing financial loss for producing countries.

The maximum allowable percent defective (MAPD) is the proportion defective at the inflection point of the OC curve. The procedure for the selection of a single sampling plan indexed through the MAPD was proposed by Soundararajan (1975). Radhakrishnan and RaviSankar (2008a, 2008b, 2009a, 2009b, 2009c, 2009d) constructed three-class attributes single, double and link sampling plans indexed through various parameters AQL, IQL, AOQL and MAPD. Suresh and Ramkumar (1996) have proposed the procedure for the selection of the parameters of a two class single sampling plan using the MAPD as the quality standard and the MAAOQ as an average outgoing quality. Radhakrishnan (2002) studied CSP plans indexed through MAAOQ. Further Radhakrishnan (2009) constructed three-class attributes single sampling plans through Six Sigma Quality Levels. Radhakrishnan and Sekkizhar (2007a) constructed sampling plans using Intervened Random Effect Poisson Distribution indexed though MAPD and MAAOQ. Radhakrishnan and Sekkizhar (2007b) also constructed sampling plans using Intervened Poisson Distribution indexed though MAPD and MAAOQ. This procedure protects the interest of the consumer in terms of incoming and outgoing quality and designed for the traditional two class single sampling plan. In this paper, an attempt is made to extend the same advantageous procedure for three class attributes single sampling plan SSP3(n,c_1,c_2).

4 Operating Procedure of the SSP3(n,c_1,c_2)

Theoretically Bray et al. (1973) suggested the following operating procedure for 3-class attributes single sampling plan, SSP3(n,c_1,c_2) having the parameters n, c_1 and c_2 :

- Step 1: Select a random sample of size n.
- Step 2: Count the number of good, marginal and bad units in the sample.
- Step 3: If the total number of marginal and bad items (d_1) found in the sample does not exceed acceptance number (c_1) for the sum of marginal and bad quality items and number of bad items (d_2) found in the sample does not exceed acceptance number (c_2) for the bad quality items then accept the lot; i.e., if $d_1 \leq c_1$ and $d_2 \leq c_2$ accept the lot; otherwise reject the lot.

5 Operating Characteristic Function

The operating characteristic (OC) function of the plan SSP3(n,c_1,c_2) is

$$Pa(p_M, p_b) = \sum_{j=0}^{c_2} \sum_{i=0}^{c_1-j} \frac{n}{(n-i-j)!i!j!} p_g^{n-i-j} p_M^i p_b^j \tag{1}$$

It is based on the trinomial probability distribution, which is a particular case of a multinomial probability distribution. This 3-class attributive plan is a general plan having three categories of quality proportions, pM, pb and pg. The conventional 2-class attribute plan is a particular case of these 3-class attribute plan when p = $p_M + p_b$ and c = c_1. The graph of this OC function is an OC surface which can be obtained by plotting the probability of acceptance (Pa) against the two quality parameters p_M and p_b.

6 Maximum Allowable Percent Defective

One of the important properties of an OC curve is that the decrease of OC function should be slower for lesser values of p in case of the good quality and steeper for larger values of p in case of the bad quality which provides a better discrimination. If p* is considered as a standard quality measure, then the above property of a desirable OC curve is exactly followed, since p* corresponds to the inflection point of an OC curve.

7 Maximum Allowable Average Outgoing Quality

The AOQ function of the single sampling plan is given by

$$AOQ = p.Pa(p) \qquad where\ \ p = p_M + p_b = (1+k).p_b, (0 < k < 1) \qquad (2)$$

The MAAOQ of a sampling plan is defined as the average outgoing quality (AOQ) at the MAPD. ie., MAAOQ = AOQ at p = p^*.

$$MAAOQ = p^*.Pa(p^*) = (p_M + p_b).Pa(p_M, p_b). \qquad (3)$$

8 Designing SSP3(n,c_1,c_2) Indexed through MAAOQ

By taking $p_M = k.p_b, (0 < k < 1)$, the OC function defined in equation(1) is converted into a function of p_b which is given by

$$Pa(p_b) = \sum_{j=0}^{c_2} \sum_{i=0}^{c_1-j} \frac{n!}{(n-i-j)!i!j!} k^i p_g^{n-i-j} p_b^{i+j} \qquad where\ \ p_g = 1-(1+k)p_b \qquad (4)$$

Differentiating (4) with respect to p_b,

$$Pa^{!}(p_b) = \sum_{j=0}^{c_2} \sum_{i=0}^{c_1-j} \frac{n!}{(n-i-j)!i!j!} k^i p_g^{n-i-j} p_b^{i+j} \left[\frac{i+j}{p_b} - \frac{n-i-j)(1+k)}{p_g}\right] \qquad (5)$$

Again differentiating (5) with respect to p_b,

$$Pa^{!!}(p_b) = \sum_{j=0}^{c_2} \sum_{i=0}^{c_1-j} \frac{n!}{(n-i-j)!i!j!} k^i p_g^{n-i-j} p_b^{i+j}.T1 \qquad (6)$$

where

$$T1 = \left[\frac{(i+j)(i+j-1)}{p_b^2} + \frac{2(1+k)(i+j)(n-i-j)}{p_b.p_g} - \frac{(1+k)^2(n-i-j)(n-1-i-j))}{p_g^2}\right]$$

9 Selection of DSP3(n,c_1,c_2) for a Specified MAAOQ

Example: For the given MAAOQ= 0.1732 and k=0.1, from Table1 one can get a three class attribute single sampling plan SSP3(12,6,3) which has the MAAOQ = 0.173265. The AOQ surface of this plan is presented in Figure 3.

Table 1: MAAOQ values of SSP3(n,c_1,c_2)

k	n	c_1	c_2	p_M	p_b	p*	Pa(p*)	MAAOQ
0.1	26	8	1	0.0040	0.0400	0.0440	0.720793	0.031715
0.1	21	8	1	0.0050	0.0500	0.0550	0.716972	0.039434
0.1	17	6	1	0.0063	0.0625	0.0688	0.712148	0.048960
0.1	26	9	2	0.0080	0.0800	0.0880	0.654264	0.057575
0.1	24	4	2	0.0087	0.0870	0.0958	0.651259	0.062361
0.1	31	11	3	0.0100	0.1000	0.1100	0.623830	0.068621
0.1	21	9	2	0.0100	0.1000	0.1100	0.648409	0.071325
0.1	26	11	3	0.0120	0.1200	0.1320	0.618891	0.081694
0.1	25	11	3	0.0125	0.1250	0.1375	0.617641	0.084926
0.1	21	9	3	0.0150	0.1500	0.1650	0.611301	0.100865
0.1	26	13	4	0.0160	0.1600	0.1760	0.595248	0.104764
0.1	26	13	5	0.0200	0.2000	0.2200	0.577486	0.127047
0.1	20	5	4	0.0208	0.2082	0.2291	0.577412	0.132271
0.1	26	13	6	0.0240	0.2400	0.2640	0.563140	0.148669
0.1	29	11	7	0.0250	0.2500	0.2751	0.556394	0.153039
0.1	12	6	3	0.0273	0.2728	0.3001	0.577395	0.173265
0.2	51	9	1	0.0040	0.0200	0.0240	0.728339	0.017480
0.2	41	9	1	0.0050	0.0250	0.0300	0.726465	0.021794
0.2	26	9	1	0.0080	0.0400	0.0480	0.720793	0.034598
0.2	21	9	1	0.0100	0.0500	0.0600	0.716972	0.043018
0.2	51	14	3	0.0120	0.0600	0.0720	0.633440	0.045608
0.2	41	14	3	0.0150	0.0750	0.0900	0.629877	0.056689
0.2	26	11	2	0.0160	0.0800	0.0960	0.654264	0.062809
0.2	31	13	3	0.0200	0.1000	0.1200	0.623830	0.074860
0.2	26	13	3	0.0240	0.1200	0.1440	0.618891	0.089120
0.2	25	11	3	0.0250	0.1250	0.1500	0.617641	0.092646
0.2	51	21	7	0.0280	0.1400	0.1680	0.576508	0.096853
0.2	21	10	3	0.0300	0.1500	0.1800	0.611301	0.110034
0.2	26	12	4	0.0320	0.1600	0.1920	0.595248	0.114288
0.2	41	20	7	0.0350	0.1750	0.2100	0.570478	0.119800
0.2	51	24	9	0.0360	0.1800	0.2160	0.561661	0.121319
0.2	31	15	6	0.0400	0.2000	0.2400	0.571078	0.137059
0.2	51	25	11	0.0440	0.2200	0.2640	0.550159	0.145242
0.2	41	20	9	0.0450	0.2250	0.2700	0.554468	0.149707
0.2	51	25	12	0.0480	0.2400	0.2880	0.545215	0.157022
0.2	53	26	13	0.0500	0.2500	0.3000	0.542084	0.162625
0.3	51	11	1	0.0060	0.0200	0.0260	0.728339	0.018937
0.3	41	10	1	0.0075	0.0250	0.0325	0.726465	0.023610
0.3	26	10	1	0.0120	0.0400	0.0520	0.720793	0.037481
0.3	21	10	1	0.0150	0.0500	0.0650	0.716972	0.046603
0.3	51	16	3	0.0180	0.0600	0.0780	0.633440	0.049408
0.3	41	15	3	0.0225	0.0750	0.0975	0.629877	0.061413
0.3	26	12	2	0.0240	0.0800	0.1040	0.654264	0.068044
0.3	31	15	3	0.0300	0.1000	0.1300	0.623830	0.081098
0.3	41	19	5	0.0375	0.1250	0.1625	0.592781	0.096327
0.3	26	12	3	0.0360	0.1200	0.1560	0.618891	0.096547
0.3	33	14	4	0.0375	0.1250	0.1625	0.603030	0.097992

Table 1(Continued ..): MAAOQ values of SSP3(n,c_1,c_2)

k	n	c_1	c_2	p_M	p_b	p*	Pa(p*)	MAAOQ
0.3	51	20	7	0.0420	0.1400	0.1820	0.576508	0.104925
0.3	41	20	6	0.0450	0.1500	0.1950	0.580533	0.113204
0.3	51	25	8	0.0480	0.1600	0.2080	0.568541	0.118257
0.3	41	20	7	0.0525	0.1750	0.2275	0.570478	0.129784
0.3	51	25	9	0.0540	0.1800	0.2340	0.561661	0.131429
0.3	46	23	9	0.0600	0.2000	0.2600	0.558508	0.145212
0.4	51	11	1	0.0080	0.0200	0.0280	0.728339	0.020394
0.4	41	11	1	0.0100	0.0250	0.0350	0.726465	0.025426
0.4	26	11	1	0.0160	0.0400	0.0560	0.720793	0.040364
0.4	21	10	1	0.0200	0.0500	0.0700	0.716972	0.050188
0.4	51	17	3	0.0240	0.0600	0.0840	0.633440	0.053209
0.4	41	17	3	0.0300	0.0750	0.1050	0.629877	0.066137
0.4	26	13	2	0.0320	0.0800	0.1120	0.654264	0.073278
0.4	41	19	4	0.0400	0.1000	0.1400	0.608429	0.085180
0.4	51	23	6	0.0480	0.1200	0.1680	0.585979	0.098445
0.4	33	16	4	0.0500	0.1250	0.1750	0.603030	0.105530
0.4	51	25	7	0.0560	0.1400	0.1960	0.576508	0.112996
0.4	41	20	6	0.0600	0.1500	0.2100	0.580533	0.121912
0.4	51	25	8	0.0640	0.1600	0.2240	0.568541	0.127353
0.4	51	25	9	0.0720	0.1800	0.2520	0.561661	0.141539
0.4	66	33	13	0.0800	0.2000	0.2800	0.548926	0.153699
0.5	51	12	1	0.0100	0.0200	0.0300	0.728339	0.021850
0.5	41	12	1	0.0125	0.0250	0.0375	0.726465	0.027242
0.5	26	11	1	0.0200	0.0400	0.0600	0.720793	0.043248
0.5	41	15	2	0.0250	0.0500	0.0750	0.662852	0.049714
0.5	51	18	3	0.0300	0.0600	0.0900	0.633440	0.057010
0.5	41	18	3	0.0375	0.0750	0.1125	0.629877	0.070861
0.5	51	21	4	0.0400	0.0800	0.1200	0.612658	0.073519
0.5	31	15	3	0.0500	0.1000	0.1500	0.623830	0.093575
0.5	51	25	6	0.0600	0.1200	0.1800	0.585979	0.105476
0.5	49	24	6	0.0625	0.1250	0.1875	0.585083	0.109703
0.5	51	25	7	0.0700	0.1400	0.2100	0.576508	0.121067
0.5	61	29	9	0.0750	0.1500	0.2250	0.566267	0.127410
0.5	51	25	8	0.0800	0.1600	0.2400	0.568541	0.136450

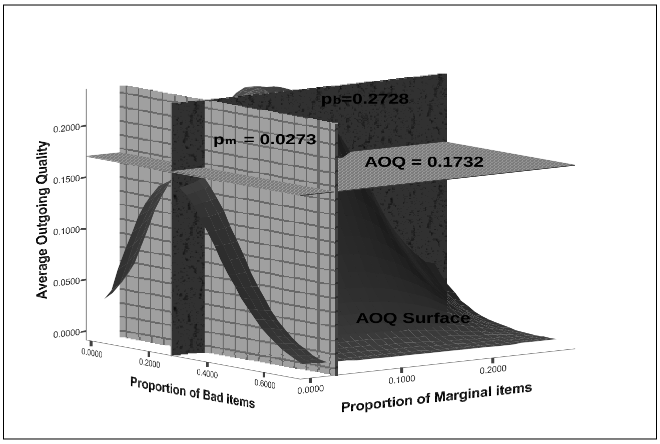

Figure 3: Average Outgoing Quality Surface of SSP3(12,6,3)

10 Conclusion

In this paper, the procedure for selecting a 3-class attributes single sampling plan indexed through MAAOQ is presented and table is constructed. These plans are very useful for the floor engineers to decide whether to accept or reject a lot based on the additional information about the marginal items also, which is an advantage of 3-class plans over 2-class plans. The study can be extended to compare the plans with the other parameters for its efficiency.

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