Repetitive Group Variables Sampling Plan indexed by Six Sigma AQL and Six Sigma AOQL

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Abstract— The concept of repetitive group sampling under attributes inspection was introduced by Sherman (1965). Senthilumar (2005) has introduced the procedures and designing repetitive group sampling plan for different combination of entry parameters namely, (AQL, LQL), (AQL, AOQL). Radhakrishnan and Sivakumaran (2008) have presented the procedure for the construction and selection of Six Sigma Repetitive Group Sampling Plan by attributes indexed through Six Sigma Quality Levels. Senthilumar and Esha Raffie (2014) have presented Six Sigma Repetitive Group Sampling Plan by variables indexed by Six Sigma Quality Levels. In this paper the procedure and tables for the selection of Six Sigma Repetitive Group Sampling Variable Inspection Plan (SSRGSVP (n; k_1, k_2)) indexed by Six Sigma AQL and Six Sigma AOQL are given. Whenever rejected lots are 100% inspected for replacement of nonconforming units.

Key words: Repetitive Group Sampling, Six Sigma, AOQ, AOQL, Six Sigma AQL and Six Sigma AOQL

I. INTRODUCTION

Repetitive Group Sampling (RGS) plan is one of the attribute sampling plans developed by Sherman (1965). Sherman has pointed out that the RGS plan will give an intermediate in sample size efficiency between the single sampling plan. A lot- by – lot rectifying inspection scheme for a series of lots calls for 100% inspection of rejected lots under application of a sampling plan. If one prefers to use a single sampling plan for variables under a rectification inspection scheme, the quality indicator for the selection of the sampling plan will be the average outgoing quality limit (AOQL), which is the worst average quality the consumer will receive in the long run, no matter what the incoming quality is. Rejected lots are often a nuisance to the producer as they result in extra work and cost. If too many lots are rejected, this will damage the reputation of the producer or supplier. From the producer point of view, he would prefer fixing an acceptable quality level (AQL) and designing sampling plan so that if the incoming product quality is maintained at AQL, most of his lot (say 99.9%) will be accepted during the sampling inspection stage itself. Thus, designing sampling inspection plan indexed by SSAQL and SSAOQL satisfies both the producer and consumer whenever rectifying inspection is necessary. Soundararajan (1981) has developed procedures and tables for the selection of single sampling plans for attributes for given AQL and AOQL. Govindaraju (1990) has developed procedures and tables for the selection of single sampling plans for variables indexed by AQL and AOQL. The concept of repetitive group sampling under attributes inspection was introduced by Sherman (1965). This concept can be extended to variables quality characteristics of study. The resulting plan would be designated as SSRGSVP and would be applied under the following conditions:

Lots are submitted for inspection serially, in the order of production from a process that turns out a constant proportion of non-conforming items.

The consumer has confidence in the supplier and there should be no reason to believe that a particular lot is poorer than the preceding lots.

When the conditions listed above are satisfied, the fraction defective in a lot will be defined by

$$p = 1 - F(v) = F(-v) \quad \text{with } v = (U - \mu) / \sigma \text{ and}$$

$$F(y)=\int_{-\infty}^{y} \frac{1}{\sqrt{2\pi}} \exp(-z^2/2)dz \tag{1}$$

Where Z~N(0,1). It is to be recalled, here, that the criterion for the σ-method variable plan has to accept the lot if $\overline{X} + k_1\sigma \le U$ or $\overline{X} - k_1\sigma \ge L$, when the upper specification limit, U or the lower specification limit, L is specified. In this section, tables and procedures for selection of Six Sigma Repetitive Group Sampling Variable Inspection Plan indexed by SSAQL and SSAOQL are given.

II. OPERATING PROCEDURE

The operating procedure of Six Sigma Repetitive Group Sampling Variables Plan is described below:

Step 1: Take a random sample of size n_σ, say ($X_1, X_2,\ldots X_{n\sigma}$) and compute

$$v = \frac{(U - \overline{X})}{\sigma}, \quad \text{where} \quad \overline{X} = \frac{1}{n_\sigma}\sum_{i=1}^{n_\sigma} X_i.$$

Step 2: Accept the lot if $v \ge k_1$ and reject the lot if $v < k_2$. ($k_2 < k_1$)

Step 3: If $k_2 \le v < k_1$ then repeat the steps 1, 2 &3.

Thus, the SSRGSV plan has the parameters of the sample size n_σ, and the acceptable criterion k_1 and k_2. The Six Sigma RGS plan for variables is simply designated as SSRGSVP (n_σ; k_1, k_2).

Variable Sampling Plan and SSAOQL procedures

The OC function of the SSRGS plan, according to Sherman (1965),

$$P_A = \frac{P_a}{P_r + p_a}$$

The fraction nonconforming in a given lot will be

$$p = F(-v) \tag{2}$$

with v= (U-μ)/σ

and its probability of acceptance will be

$$P_A(p_1) = F(w_1, w_2)$$

$$\text{where} \quad w_1 = (v_1 - k_{1\sigma})\sqrt{n_\sigma} \tag{3}$$

$$w_2 = (v_2 - k_{2\sigma})\sqrt{n_\sigma} \tag{4}$$

If the quality of the accepted lot is p and all defective units found in the rejected lots are replaced by non-defective units in a rectifying inspection plan, the Six

Sigma average outgoing quality (SSAOQ) can be approximated as

$$SSAOQ = p\, P_A(p) \quad (5)$$

If p_m is the proportion nonconforming items at which SSAOQ is maximum, one has

$$SSAOQL = p_m\, P_A(p_m) \quad (6)$$

If SSAQL (p_1) is prescribed, then the corresponding value of v_{SSAQL} or v_1 will be fixed and if $P_A(p_1)$ is fixed at 99.99966%, that is (1-α). Where, $\alpha = 0.0000034\times10^{-6}$. Hence we have $P_A(p_1) = (1-\alpha)$

So that for given values of n_σ, w_1, w_2, and SSAQL, $k_{1\sigma}$, $k_{2\sigma}$ are determined.

III. Selection of Known Σ SSRGSVP (N_Σ; $K_{1\Sigma}$, $K_{2\Sigma}$) for Given SSAQL and SSAOQL

Table 1 is used for selection of σ- method SSRGS variables plan. For example, if the SSAQL is fixed at $p_1=0.00005$ and the SSAOQL is fixed at $p_2=0.00006$, Table 1 yields $n_\sigma = 2304$, $k_{1\sigma} = 2.976$ and $k_{2\sigma} = 2.826$, which is associated with 4.5 sigma level.

The user of Table 1 should understand the limitations of plans indexed by SSAOQL. Sampling with rectifying of rejected lots on the one hand reduces the average percentage of nonconforming items in the lots, but on the other hand introduces non-homogeneity in the series of lots finally accepted. That is, any particular lot will have a quality of p% or 0% nonconforming depending on whether the lot is accepted or rectified. Thus the assumption underlying the SSAOQL principle is that the homogeneity in the qualities of individual lots is unimportant and only the average quality matters. For plans listed in Table 1, if the individual lot quality happens to be the product quality p_m at which SSAOQL occurs, then the associated probability of acceptance will be poor. Table 2 gives $P_a(p_m)$ values of plans given in Table 1. For example, for SSAQL of $p_1 = 0.00001$ and SSAOQL of $p_2 = 0.00005$, Table 2 gives $P_a(p_m) = 0.54$. Then $p_m = SSAOQL/ P_a(p_m) = 0.000092$. In order to avoid such inconvenience, the producer should maintain the process quality more or less at the SSAQL. The higher rate of rejection of lots at $p = p_m$ will also indirectly put pressure on the producer to improve the submitted quality.

V. Six Sigma Repetitive Group Sampling Variables Plan with Unknown σ

Whenever the standard deviation is unknown, we should use the sample standard deviation S instead of σ. In this case, the plan operates as follows.

Step 1: Take a random sample of size n_σ, say $(X_1, X_2, \ldots X_{n\sigma})$ and compute

$$v = \frac{(U-\bar{X})}{S}, \text{ where } S = [\sum (x_i - \bar{x})^2/(n-1)]^{1/2} \text{ and } \bar{X} = \frac{1}{n_\sigma}\sum_{i=1}^{n_\sigma} X_i.$$

Step 2: Accept the lot if $v \geq k_1$ and reject the lot if $v < k_2$. ($k_2 < k_1$)

Step 3: If $k_2 \leq v < k_1$ then repeat the steps 1, 2 &3.

Thus, the SSRGSV plan has the parameters of the sample size n_σ, and the acceptable criterion k_1 and k_2. Under the assumptions for Six Sigma Repetitive Group Variables Sampling Plan stated, the probability of acceptance P_A (p), of a lot is given in the equation (1) and P_a and P_r respectively are

$$P_a = \int_{-\infty}^{w_1} \frac{1}{\sqrt{2\pi}} \exp(-z^2/2)dz$$

and

$$P_r = \int_{w_2}^{\infty} \frac{1}{\sqrt{2\pi}} \exp(-z^2/2)dz = \int_{-\infty}^{w_2} \frac{1}{\sqrt{2\pi}} \exp(-z^2/2)dz$$

with

$$w_1 = \frac{U-k_1S-\mu}{S} \cdot \frac{1}{\sqrt{\left(\frac{1}{n_s} + \frac{k_1^2}{2n_s}\right)}}$$

$$w_2 = \frac{U-k_2S-\mu}{S} \cdot \frac{1}{\sqrt{\left(\frac{1}{n_s} + \frac{k_2^2}{2n_s}\right)}}$$

VI. Selection of Unknown σ SSRGSVP (NΣ; K1Σ, K2Σ) for Given SSAQL and SSAOQL

Table 1 also gives such matched s-method plan. For example, for given SSAQL of $p_1 = 0.0001$ and SSAOQL of $p_2 = 0.0002$, one obtains the parameters of the s-method plan from Table 1 to be $n_s = 5495$, $k_{1\sigma} = 2.582$ and $k_{2\sigma} = 2.432$, which is associated with 4.8 sigma level.

IV. Construction of Table 1

For constructing Table 1, a trial value of p_m is assumed and the probability of acceptance at p_m is found using (6) as

$$P_A(p_m) = SSAOQL / p_m$$

The auxiliary variables v_m, w_{1m} and w_{2m} corresponding to the values of p_m and $P_A(p_m)$ respectively, are found using (1) and (2). For given values of p_1, determine the values of v_1, w_1 and w_2 using the approximation (Abramwitz and Stegun (1972)) for the ordinate of the cumulative normal distribution. With the values of v_m, w_{1m} and w_{2m}, the following equation is used for calculating n_σ.

$$p_a[\sqrt{\exp(v_m^2 - w_2^2)} - \sqrt{\exp(v_m^2 - w_1^2)}]] / (p_r + p_a)^2] \quad (7)$$

where

$$P_a = \int_{-\infty}^{w_1} \frac{1}{\sqrt{2\pi}} \exp(-z^2/2)dz$$

and

$$P_r = \int_{w_2}^{\infty} \frac{1}{\sqrt{2\pi}} \exp(-z^2/2)dz = 1 - \int_{-\infty}^{w_2} \frac{1}{\sqrt{2\pi}} \exp(-z^2/2)dz$$

Equation (7) is the formula for finding the sample size of a known σ SSRGS variables plan. With the values of n obtained from (7), it is then checked to see whether the assumed value of p_m corresponds to the proportion non-conforming at which the SSAOQL occurs or not. That is, it is checked to see whether or not the trial value of p_m satisfies the following condition.

$$(AOQL) - [p_m^2[(p_r + p_a)\sqrt{n_\sigma \exp(v_m^2 - w_1^2)} + p_a[\sqrt{n_\sigma \exp(v_m^2 - w_2^2)} - \sqrt{n_\sigma \exp(v_m^2 - w_1^2)}]] / (p_r + p_a)^2] = 0 \quad (8)$$

Equation (3.18) was obtained from the following relation

$$\frac{d(SSAOQ)}{dp} = P_A(p) + p\frac{dP_A(p)}{dp} = 0 \quad (9)$$

In which

$$\sqrt{n_\sigma} = (AOQL) / [p_m^2[(p_r + p_a)\sqrt{\exp(v_m^2 - w_1^2)} +$$

$$\frac{dP_A(P)}{dp} = [[(p_r + p_a)(-1)\sqrt{n_\sigma \exp(v_m^2 - w_1^2)} +$$

$$p_a[\sqrt{n_\sigma \exp(v_m^2 - w_2^2)} - \sqrt{n_\sigma \exp(v_m^2 - w_1^2)}]] / (p_r + p_a)^2] \quad (10)$$

If the assumed value of p_m does not satisfy (9), then another trial value of p_m is obtained from (9) by numerical methods. The methods of successive substitution are often found to give good results and (9) is rewritten for this purpose as

$$p_m = AOQL / [p_m[(p_r + p_a)\sqrt{n_\sigma \exp(v_m^2 - w_1^2)} + p_a[\sqrt{n_\sigma \exp(v_m^2 - w_2^2)} - \sqrt{n_\sigma \exp(v_m^2 - w_1^2)}]] / (p_r + p_a)^2] \quad (11)$$

After determining the next trial value of p_m, again the values of v_m, w_{1m}, w_{2m} and n_σ are found and the condition (8) rechecked. This iterative procedure continues until the convergence of p_m is achieved. Then the value of $k_{1\sigma}$ and $k_{2\sigma}$ is obtained from (3) and (4).

For obtaining the values of v_1, w_1 and w_2, the approximation for the ordinate of the cumulative normal distribution available in Abramowitz and Stegun (1972) was used.

The S-method plans matching the σ-method plans were obtained using computer search routine through C++ programme. For selected combinations of SSAQL and SSAOQL, Table 1 was constructed following the above iterative procedure.

The iterative procedure given above may also be used to determine a Six Sigma Repetitive Group Sampling plan for given Six Sigma Indifference Quality Level (SSIQL) and SSAOQL as well as for given Six Sigma Limiting Quality Level(SSLQL) and SSAOQL with appropriate auxiliary variables v, w_1 and w_2.

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SSAQL (%)	SSAOQL (%)	n_σ	$k_{1\sigma}$	$k_{2\sigma}$	σ - Level	n_s	k_{1s}	k_{2s}	σ - Level
	0.0002	2523	4.721	4.571	4.4	29758	4.721	4.571	5.1
	0.0003	2147	4.542	4.392	4.4	23572	4.542	4.392	5.1
	0.0004	1543	4.473	4.323	4.3	16468	4.473	4.323	5.0
	0.0005	1359	4.419	4.269	4.2	14184	4.419	4.269	4.9
	0.0006	1154	4.374	4.224	4.2	11820	4.375	4.225	4.9
	0.0007	971	4.335	4.185	4.1	9783	4.336	4.186	4.8
0.0001	0.0008	928	4.302	4.152	4.1	9220	4.303	4.153	4.8
	0.0009	825	4.272	4.122	4.1	8093	4.273	4.123	4.8
	0.001	807	4.245	4.095	4.1	7825	4.246	4.096	4.8
	0.002	782	4.063	3.913	4.1	7002	4.064	3.914	4.8
	0.003	725	3.952	3.802	4.1	6175	3.953	3.803	4.7
	0.004	683	3.871	3.721	4.0	5605	3.872	3.722	4.7
	0.005	647	3.808	3.658	4.0	5156	3.809	3.659	4.7
	0.0003	2474	4.457	4.307	4.4	26231	4.457	4.307	5.1
	0.0004	1669	4.387	4.237	4.3	17188	4.387	4.237	5.0
	0.0005	1485	4.334	4.184	4.3	14956	4.334	4.184	4.9
	0.0006	1280	4.288	4.138	4.2	12642	4.288	4.138	4.9
	0.0007	1097	4.250	4.100	4.2	10660	4.251	4.101	4.9
	0.0008	1054	4.217	4.067	4.2	10097	4.218	4.068	4.8
0.0002	0.0009	951	4.187	4.037	4.1	8993	4.188	4.038	4.8
	0.001	933	4.159	4.009	4.1	8715	4.160	4.010	4.8
	0.002	908	3.977	3.827	4.1	7822	3.978	3.828	4.8
	0.003	851	3.866	3.716	4.1	6967	3.867	3.717	4.8
	0.004	809	3.785	3.635	4.1	6378	3.786	3.636	4.7
	0.005	773	3.721	3.571	4.1	5912	3.722	3.572	4.7
	0.006	675	3.668	3.518	4.1	5033	3.669	3.519	4.7
	0.0004	2495	4.297	4.147	4.4	24736	4.297	4.147	5.1
0.0003	0.0005	1911	4.243	4.093	4.4	18513	4.243	4.093	5.0
	0.0006	1334	4.199	4.049	4.2	12679	4.199	4.049	4.9
	0.0007	1151	4.159	4.009	4.2	10752	4.160	4.010	4.9

	0.0008	1108	4.126	3.976	4.2	10201	4.127	3.977	4.9
	0.0009	1005	4.096	3.946	4.2	9131	4.097	3.947	4.8
	0.001	987	4.069	3.919	4.1	8861	4.070	3.920	4.8
	0.002	962	3.886	3.736	4.2	7949	3.887	3.737	4.8
	0.003	905	3.775	3.625	4.1	7101	3.776	3.626	4.8
	0.004	863	3.694	3.544	4.1	6516	3.695	3.545	4.8
	0.005	827	3.630	3.480	4.1	6054	3.631	3.481	4.7
	0.006	729	3.577	3.427	4.1	5200	3.578	3.428	4.7
	0.007	691	3.531	3.381	4.1	4819	3.532	3.382	4.7
0.0004	0.0005	1994	4.051	3.901	4.4	17758	4.051	3.901	5.0
	0.0006	1417	4.005	3.855	4.3	12362	4.005	3.855	4.9
	0.0007	1234	3.968	3.818	4.2	10587	3.969	3.819	4.9
	0.0008	1191	3.934	3.784	4.2	10061	3.935	3.785	4.9
	0.0009	1088	3.904	3.754	4.2	9065	3.905	3.755	4.8
	0.001	1070	3.877	3.727	4.2	8805	3.878	3.728	4.8
	0.002	1045	3.694	3.544	4.2	7890	3.695	3.545	4.8
	0.003	988	3.583	3.433	4.2	7069	3.584	3.434	4.8
	0.004	946	3.502	3.352	4.2	6502	3.503	3.353	4.8
	0.005	910	3.437	3.287	4.2	6054	3.438	3.288	4.8
	0.006	812	3.384	3.234	4.1	5259	3.385	3.235	4.7
	0.007	697	3.338	3.188	4.1	4408	3.339	3.189	4.7
0.0005	0.0006	1530	3.912	3.762	4.3	12795	3.912	3.762	4.9
	0.0007	1478	3.873	3.723	4.3	12140	3.873	3.723	4.9
	0.0008	1295	3.840	3.690	4.3	10475	3.841	3.691	4.9
	0.0009	1252	3.810	3.660	4.2	9987	3.811	3.661	4.9
	0.001	1149	3.783	3.633	4.2	9050	3.784	3.634	4.8
	0.002	1131	3.600	3.450	4.2	8159	3.601	3.451	4.8
	0.003	1106	3.488	3.338	4.2	7549	3.489	3.339	4.8
	0.004	1049	3.408	3.258	4.2	6877	3.409	3.259	4.8
	0.005	1007	3.343	3.193	4.2	6386	3.344	3.194	4.8
	0.006	971	3.290	3.140	4.2	5991	3.291	3.141	4.8
	0.007	751	3.244	3.094	4.1	4523	3.245	3.095	4.7
	0.008	758	3.204	3.054	4.1	4470	3.205	3.055	4.7
0.001	0.002	2242	3.622	3.472	4.5	16349	3.622	3.472	5.0
	0.003	1217	3.490	3.340	4.3	8315	3.491	3.341	4.8
	0.004	1160	3.409	3.259	4.3	7609	3.410	3.260	4.8
	0.005	1118	3.345	3.195	4.3	7097	3.346	3.196	4.8
	0.006	1082	3.291	3.141	4.3	6679	3.292	3.142	4.8
	0.007	862	3.245	3.095	4.2	5194	3.246	3.096	4.7
	0.008	869	3.120	2.970	4.2	4899	3.121	2.971	4.7
	0.009	913	3.089	2.939	4.2	5061	3.090	2.940	4.7
0.005	0.006	2304	2.976	2.826	4.5	12002	2.976	2.826	5.0
	0.007	1308	2.931	2.781	4.4	6644	2.932	2.782	4.8
	0.008	1266	2.890	2.740	4.3	6284	2.891	2.741	4.8
	0.009	1206	2.855	2.705	4.3	5868	2.856	2.706	4.8
	0.01	942	2.821	2.671	4.3	4495	2.822	2.672	4.7
	0.02	907	2.599	2.449	4.3	3797	2.600	2.450	4.7
	0.03	874	2.462	2.312	4.3	3365	2.463	2.313	4.7
	0.04	816	2.361	2.211	4.3	2949	2.362	2.212	4.7
	0.05	756	2.282	2.132	4.3	2598	2.283	2.133	4.6
	0.06	721	2.254	2.104	4.2	2433	2.254	2.104	4.6
	0.07	707	2.155	2.005	4.3	2236	2.155	2.005	4.6
	0.08	683	2.014	1.864	4.3	1967	2.014	1.864	4.6
	0.09	542	2.009	1.859	4.2	1556	2.009	1.859	4.5
0.01	0.02	1327	2.581	2.431	4.4	5495	2.582	2.432	4.8
	0.03	938	2.444	2.294	4.3	3571	2.445	2.295	4.7
	0.04	880	2.343	2.193	4.3	3144	2.344	2.194	4.7
	0.05	820	2.264	2.114	4.3	2785	2.265	2.115	4.7

	0.06	785	2.236	2.086	4.3	2618	2.236	2.086	4.6
	0.07	771	2.137	1.987	4.3	2410	2.137	1.987	4.6
	0.08	747	1.996	1.846	4.3	2125	1.996	1.846	4.6
	0.09	606	1.991	1.841	4.2	1718	1.991	1.841	4.6
0.05	0.06	1043	2.227	2.077	4.4	3458	2.227	2.077	4.7
	0.07	1029	2.128	1.978	4.4	3198	2.128	1.978	4.7
	0.08	1005	1.987	1.837	4.4	2842	1.987	1.837	4.7
	0.09	864	1.982	1.832	4.3	2435	1.982	1.832	4.7

Table 1: SSRGSVP with known and unknown σ indexed by SSAQL and SSAOQL

SSAOQL (%)	SSAQL (%)								
	0.0001	0.0002	0.0003	0.0004	0.0005	0.001	0.005	0.01	0.05
0.0002	0.97								
0.0003	0.95	0.97							
0.0004	0.94	0.96	0.98						
0.0005	0.87	0.94	0.96	0.97					
0.0006	0.75	0.87	0.89	0.90	0.91				
0.0007	0.52	0.76	0.78	0.79	0.88				
0.0008	0.50	0.52	0.54	0.55	0.64				
0.0009	0.47	0.51	0.53	0.53	0.62				
0.001	0.45	0.47	0.49	0.50	0.59				
0.002	0.40	0.45	0.47	0.48	0.57	0.64			
0.003	0.37	0.41	0.42	0.43	0.52	0.62			
0.004	0.34	0.37	0.39	0.40	0.49	0.57			
0.005	0.23	0.35	0.36	0.37	0.46	0.54			
0.006		0.23	0.25	0.26	0.35	0.51	0.61		
0.007			0.21	0.22	0.31	0.40	0.50		
0.008					0.27	0.36	0.46		
0.009						0.32	0.42		
0.01							0.38		
0.02							0.35	0.37	
0.03							0.32	0.34	
0.04							0.29	0.31	
0.05							0.27	0.29	
0.06							0.24	0.26	0.29
0.07							0.21	0.23	0.26
0.08							0.19	0.21	0.24
0.09							0.17	0.19	0.22

Table 2: Pa (pm) Values of known σ plan