Selection and Construction of Six Sigma TNT Variables Sampling Scheme (n_σ; k_T, k_N) indexed by Six Sigma Quality Levels

Dr. B. Esha Raffie[1] and Dr. D. Senthilkumar[2]

[1]*Assistant Professor, PSG College of Arts & Science, Coimbatore – 641 014.*

[2]*Head & Associate Professor, PSG College of Arts & Science, Coimbatore – 641 014.*

Abstract

This article gives selection of Six Sigma Tightened- Normal – Tightened Variables Sampling Scheme (SSTNTVSS (n_σ; k_T, k_N)) indexed by Six Sigma AQL and Six Sigma AOQL. The procedure of tables constructed for easy selection of system given indexed by six sigma quality levels by known and unknown σ at Six Sigma levels.

Keywords - *Tightened- Normal – Tightened Scheme, Variables Sampling, Six Sigma AOQ, Six Sigma AQL and Six Sigma AOQL.*

I. INTRODUCTION

A lot- by – lot rectifying inspection scheme for a series of lots calls for 100% inspection of rejected lots under application of 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. Later Soundarajan and Palanivel (2000) have developed procedures and tables for the selection of quick switching single sampling variables systems indexed by AQL and AOQL. Based on above article Senthilkumar and Esha Raffie (2017) have constructed SSQSVSS (n_σ; $k_{T\sigma}$, $k_{N\sigma}$) indexed by Six Sigma AQL and Six Sigma AOQL. Senthilkumar and Esha Raffie (2018) have constructed six sigma modified quick switching variables sampling system [SSMQSVSS-r ($n_{T\sigma}$, $n_{N\sigma}$; k_σ), r=2 and 3] indexed by six sigma quality levels of SSAQL and SSAOQL. Muthuraj and Senthilkumar (2006) have developed the procedures and constructed tables for the selection of tightened – normal – tightened variables sampling scheme indexed by AQL and AOQL. This concept can be extended to variables quality characteristics of the study, the resulting plan would be designated as SSTNTVSS and would be applied under the following **conditions**:

i) Production is steady so that results on current, preceding and succeeding lots are broadly indicative of a continuing process.

ii) Lots are submitted substantially in the order of production.

iii) Inspection is by variables, with quality of an individual item defined in terms of fraction defective.

A. Basic assumptions

a) The quality characteristics is represented by a random variable X measurable on a continuous scale.

b) Distribution of X is normal with mean μ and standard deviation σ.

c) An upper limit U, has been specified and a product is qualified as defective when X>U.[when the lower limit L is specified, the product is a defective one if X<L].

d) The Purpose of inspection is to control the fraction defective, p in the lot inspected.

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

$p = 1 - F(v) = F(-v)$ with v $=\mu$) and

$$F(y) = \int_{-\infty}^{y_1} \frac{1}{\sqrt{2\pi}} e^{-z^2/2}\, dz \qquad (1)$$

where z ~ N (0, 1). Here the decision criterion for the σ- method variables plan is to accept the lot if $\bar{X} + k\sigma \leq U$, where U is the upper specification limit or if $\bar{X} + k\sigma \geq L$, where L is the lower specification limit.

B. SSTNTVSS with known σ variable plan as the reference plan

The operating procedure of SSTNTVSS(n_σ; $k_{T\sigma}$, $k_{N\sigma}$) are described below.

Step 1: Inspect under tightened inspection using the single sampling plan with sample size $n_{T\sigma}$ and the acceptance constant k_T. Accept the individual lot, if $\bar{X} + k_T\sigma \leq U$ or $\bar{X} - k_T\sigma \geq L$ where $\bar{x}$ is the sample mean. If t lots in a row are accepted, switch to normal inspection (Step 2).

Step 2: Inspect under normal inspection using the single sampling plan with sample size $n_{N\sigma}$ and the acceptance constant k_N. Reject the individual lot, if $\bar{X} + k_N\sigma > U$ or $\bar{X} - k_N\sigma < L$ where $\bar{x}$ is the sample mean. When an additional lot is rejected in the next s lots after a rejection, switch to tightened inspection.

Thus, a SSTNTVSS scheme where tightening is based on the acceptance constants is specified by the parameters n_σ, $k_{T\sigma}$, $k_{N\sigma}$, s and t, where n_σ is the sample size and $k_{N\sigma}$ and $k_{T\sigma}$ are the acceptance constants of the variables sampling plan under normal and tightened inspection respectively, t is the criterion for switching to normal inspection, and s is the criterion for switching to tightened inspection. The Six Sigma TNT variables sampling scheme is simply designated as SSTNTVSS (n_σ; $k_{T\sigma}$, $k_{N\sigma}$).

When s =4 and t = 5, the OC function of the TNTVSS becomes the scheme OC function of MIL – STD – 105D that involves tightened and normal inspections was derived by Dodge (1965), Hald and Thyregod (1965) and Stephen and Larson (1967).

II. OPERATING CHARACTERISTIC FUNCTION

According to Calvin (1977), the OC function of the TNT scheme is given by

$$P_a(p) = \frac{P_T(1-P_N^S)(1-P_T^t)(1-P_N) + P_N P_T^t(1-P_T)(2-P_N^S)}{(1-P_N^S)(1-P_T^t)(1-P_N) + P_T^t(1-P_T)(2-P_N^S)} \quad (2)$$

where P_T and P_N are the proportion of lots expected to be accepted using tightened (n_σ, k_T) and normal (n_σ, k_N) variables single sampling plans respectively. Under the assumption of normal distribution, the expression for P_T and P_N are given by

$$P_T = \Pr\,[(U - \bar{X})/\sigma \geq k_T] \quad (3)$$

And

$$P_N = P\,[(U - \bar{X})/\sigma \geq k_N] \quad (4)$$

respectively. Equations (3) and (4) are substituted in (2) to find $P_a(p)$ values for given p, s, t, n, k_T, and k_N. As the individual values of X follows normal distribution with mean μ and variance σ^2, the expressions given in (8.3) and (8.4) can be restated as

$$P_T = \int_{-\infty}^{w_T} \frac{1}{\sqrt{2\pi}} e^{(-z^2/2)}\, dz \quad \text{and}$$

$$P_N = \int_{-\infty}^{w_N} \frac{1}{\sqrt{2\pi}} e^{(-z^2/2)}\, dz$$

respectively, with

$$w_T = \sqrt{n_\sigma}\,(U - k_T\sigma - \mu)/\sigma = (v - k_T)\sqrt{n_\sigma},$$

$$w_N = \sqrt{n_\sigma}\,(U - k_N\sigma - \mu)/\sigma = (v - k_N)\sqrt{n_\sigma} \quad \text{and}$$

$$v = (U - \mu)/\sigma$$

To determine the values of n_σ, $k_{T\sigma}$, and $k_{N\sigma}$ the given values of p_1, p_2, α and β should satisfy the following two equations. That is,

$$P_a(p) = \frac{P_T(1-P_N^S)(1-P_T^t)(1-P_N) + P_N P_T^t(1-P_T)(2-P_N^S)}{(1-P_N^S)(1-P_T^t)(1-P_N) + P_T^t(1-P_T)(2-P_N^S)} \quad (5)$$

III. SSAOQL PROCEDURES

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

$$SSAOQ = pP_a(p) \quad (6)$$

Where $P_a(p)$is defined in the equation (2). If p_m is the proportion nonconforming items at which SSAOQ is maximum, one has

$$SSAOQL = p_m P_a(p_m) \quad (7)$$

If SSAQL (p_1) is prescribed, then the corresponding value of v_{SSAQL} or v_1 will be fixed and if $P_a(p)$ is fixed at 99.99966%, that is (1-α). Where, α = $0.0000034\text{x}10^{-6}$. Hence we have $P_a(p_1)$ = (1-α) which is obtained from equation (5), and v_1 satisfies

$$w_N = (v_1 - k_{N\sigma})\sqrt{n_\sigma} \quad (8)$$

and

$$w_T = (v_1 - k_{T\sigma})\sqrt{n_\sigma} \quad (9)$$

so that for given values of n_σ, w_N, w_T and SSAQL, $k_{T\sigma}$, $k_{N\sigma}$ are determined.

A. Selection of known σ SSTNTVSS(n_σ; $k_{T\sigma}$, $k_{N\sigma}$) for given SSAQL and SSAOQL

Table 1 is used for selection of σ- method SSTNTVSS. For example, if the SSAQL is fixed at p_1=0.00009 and the SSAOQL is fixed at 0.0001, Table 1 yields n_σ = 2799, $k_{T\sigma}$ = 3.699 and $k_{N\sigma}$ = 3.635, which is associated with 4.5 sigma level of SSTNTVSS (n_σ; $k_{T\sigma}$, $k_{N\sigma}$).

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=0.00004 and SSAOQL =0.0002, Table 8.3 gives $P_a(p_m)$ = 0.67. Then p_m = SSAOQL/ $P_a(p_m)$ = 0.00037. In order to avoid such inconvenience, the producer should maintain the process quality more or less at the SSAQL. The high rate of rejection of lots at p = p_m will also indirectly put pressure on the producer to improve the submitted quality.

B. Selection of unknown σ SSTNTVSS(n_σ; $k_{T\sigma}$, $k_{N\sigma}$) for given SSAQL and SSAOQL

Table 1 also gives such matched S-method plan. For example, for given SSAQL of p_1=0.00007 and SSAOQL 0.0003, one obtains the parameters of the S-method plan from Table 5.2 to be n_s = 2509, $k_{T\sigma}$ = 3.813 and $k_{N\sigma}$ = 3.749, which is associated with 4.5 sigma level of SSTNTVSS(n_σ; $k_{T\sigma}$, $k_{N\sigma}$).

IV. CONSTRUCTION OF TABLE 1 AND 2

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

$$P_a(p_m) = SSAOQL / p_m \qquad (10)$$

The auxiliary variables v_m, w_{Nm} and w_{Tm} corresponding to the values of p_m and $P_a(p_m)$ respectively, are found using (1) to (4). For given values of p_1, determine the values of v_1, w_N and w_T using the approximation (Abramwitz and Stegun (1972)) for the ordinate of the cumulative normal distribution. With the values of v_m, w_{Nm} and w_{Tm}, the following equations are derived which Muthuraj and Senthilkumar(2006) used for calculating n_σ.

$$\sqrt{n_\sigma} = (-AOQL)/(p_m^2 (P'_{T_1} G + P'_N H)/(A+B)^2 \qquad (11)$$

where

$$P'_{T_1} = -\sqrt{(\exp(v_m^2 - w_{Tm}^2)} \qquad (12)$$

$$P'_{N_1} = -\sqrt{(\exp(v_m^2 - w_{Nm}^2)} \qquad (13)$$

$$G = (A^2 + AB) - [(P_T - P_N)(AB_1 - AB_3 + BA_2)] \qquad (14)$$

$$H = (B^2 + AB) + [(P_T - P_N)(AB_2 - BA_1 - BA_3)] \qquad (15)$$

$$A = (1-P_N^s)(1-P_T^t)(1-P_N) \qquad (16)$$

$$B = P_T^t(1-P_T)(1-2P_N^s) \qquad (17)$$

$$A_1 = (1-P_T^t)(1-P_N)s\ P_N^{s-1} \qquad (18)$$

$$A_2 = (1-P_N^s)(1-P_T)t\ P_T^{t-1} \qquad (19)$$

$$A_3 = (1-P_T^t)(1-P_N^s) \qquad (20)$$

$$B_1 = (1-P_T)(2-P_N^s)t\ P_T^{t-1} \qquad (21)$$

$$B_2 = P_T^t(1-P_T)s\ P_N^{s-1} \qquad (22)$$

$$B_3 = P_T^t(2-P_N^s) \qquad (23)$$

Equation (11) is the formula for finding the sample size of a known σ SSTNTVSS. With the values of n_σ obtained from (11), 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.

$$AOQL + [(p_m^2 (P'_{T_1} G + P'_N H)/(A+B)^2] = 0 \qquad (24)$$

where $$P'_{T_1} = -\sqrt{n_\sigma \exp(v_m^2 - w_{Tm}^2)} \qquad (25)$$

$$P'_{N_1} = -\sqrt{n_\sigma \exp(v_m^2 - w_{Nm}^2)} \qquad (26)$$

The value of G, H, A and B are obtained from equation (14) to (15). The Equation (24) was obtained from the following relation

$$\frac{d(SSAOQ)}{dp} = P_a(p) + p\frac{dP_a(p)}{dp} = 0 \qquad (27)$$

in which

$$\frac{d(SSAOQ)}{dp} = \frac{P'_T G + P'_N H}{(A+B)^2} \qquad (28)$$

If assumed value of p_m does not satisfy (27), then another trial value of p_m is obtained from (27) by numerical methods. The methods of successive substation is often found to give good results and (27) is rewritten for this purpose as

$$p_m = (-AOQL)/[p_m (P'_T G + P'_N H)/(A+B)^2] \qquad (29)$$

After determining the next trial value of p_m, again the values of v_m, w_{Nm}, w_{Tm} and n_σ are found and the condition (24) rechecked. This iterative procedure continues until the convergence of p_m is achieved. Then the value of $k_{N\sigma}$ and $k_{T\sigma}$ are obtained from (3) and (4).

For obtaining the values of v_1, w_N and w_T, 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.

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

SSAQL(p_1)	SSAOQL	n_σ	$k_{T\sigma}$	$k_{N\sigma}$	σ - Level	n_s	k_{Ts}	k_{Ns}	σ - Level
0.00001	0.00002	1112	4.345	4.281	4.2	11455	4.345	4.281	4.9
	0.00003	991	4.332	4.268	4.1	10153	4.332	4.268	4.8
	0.00004	878	4.317	4.253	4.1	8939	4.317	4.253	4.8
	0.00005	739	4.305	4.241	4.0	7486	4.305	4.241	4.8
	0.00006	587	4.294	4.230	3.9	5917	4.294	4.230	4.7
	0.00007	422	4.279	4.215	3.8	4227	4.279	4.215	4.6
	0.00008	244	4.264	4.200	3.6	2429	4.264	4.200	4.4
	0.00009	254	4.251	4.187	3.6	2515	4.251	4.188	4.4
	0.0001	243	4.236	4.172	3.6	2390	4.236	4.173	4.4
	0.0002	217	4.221	4.157	3.6	2121	4.221	4.158	4.4
	0.0003	195	4.206	4.142	3.5	1894	4.207	4.143	4.3
	0.0004	174	4.191	4.127	3.5	1679	4.192	4.128	4.3
	0.0005	141	4.176	4.112	3.4	1352	4.177	4.113	4.2
0.00002	0.00003	1533	4.338	4.274	4.3	15746	4.338	4.274	5.0
	0.00004	1120	4.262	4.198	4.2	11140	4.262	4.198	4.9
	0.00005	981	4.247	4.183	4.1	9695	4.247	4.183	4.8
	0.00006	829	4.235	4.171	4.1	8151	4.235	4.171	4.8

	0.00007	664	4.223	4.159	4.0	6496	4.223	4.159	4.7
	0.00008	257	4.208	4.144	3.6	2498	4.208	4.145	4.4
	0.00009	267	4.193	4.129	3.7	2578	4.193	4.130	4.4
	0.0001	256	4.180	4.117	3.6	2459	4.181	4.117	4.4
	0.0002	230	4.165	4.101	3.6	2195	4.166	4.102	4.4
	0.0003	208	4.150	4.086	3.6	1972	4.151	4.087	4.4
	0.0004	187	4.135	4.071	3.5	1761	4.136	4.072	4.3
	0.0005	154	4.120	4.056	3.4	1441	4.121	4.057	4.3
0.00003	0.00004	1807	4.268	4.204	4.3	18018	4.268	4.204	5.0
	0.00005	1302	4.192	4.128	4.2	12566	4.192	4.128	4.9
	0.00006	1150	4.176	4.113	4.2	11027	4.176	4.113	4.9
	0.00007	985	4.164	4.100	4.1	9395	4.164	4.101	4.8
	0.00008	578	4.153	4.089	4.0	5485	4.153	4.089	4.7
	0.00009	388	4.137	4.074	3.8	3658	4.138	4.074	4.6
	0.0001	370	4.122	4.058	3.8	3465	4.122	4.059	4.5
	0.0002	244	4.109	4.046	3.6	2272	4.110	4.046	4.4
	0.0003	222	4.094	4.030	3.6	2054	4.095	4.031	4.4

Table 1 (continued…)

SSAQL(p_1)	SSAOQL	n_σ	$k_{T\sigma}$	$k_{N\sigma}$	σ - Level	n_s	k_{Ts}	k_{Ns}	σ - Level
0.00003	0.0004	201	4.079	4.015	3.6	1847	4.080	4.016	4.3
	0.0005	167	4.065	4.001	3.5	1525	4.066	4.002	4.3
0.00004	0.00005	2086	4.122	4.058	4.4	19530	4.122	4.058	5.0
	0.00006	1334	4.106	4.042	4.2	12406	4.106	4.042	4.9
	0.00007	1002	4.094	4.030	4.1	9268	4.094	4.030	4.8
	0.00008	595	4.082	4.018	4.0	5475	4.082	4.018	4.7
	0.00009	405	4.067	4.003	3.8	3702	4.067	4.003	4.6
	0.0001	387	4.052	3.988	3.8	3513	4.052	3.988	4.6
	0.0002	261	4.039	3.975	3.7	2356	4.039	3.975	4.4
	0.0003	239	4.023	3.960	3.6	2143	4.024	3.960	4.4
	0.0004	218	4.008	3.944	3.6	1941	4.009	3.945	4.4
	0.0005	184	3.994	3.930	3.5	1628	3.995	3.931	4.3
0.00005	0.00006	2143	4.035	3.972	4.4	19317	4.035	3.972	5.0
	0.00007	1411	4.023	3.959	4.3	12649	4.023	3.959	4.9
	0.00008	622	4.011	3.947	4.0	5546	4.011	3.947	4.7
	0.00009	432	3.996	3.932	3.9	3826	3.996	3.932	4.6
	0.0001	414	3.981	3.918	3.8	3643	3.982	3.918	4.6
	0.0002	288	3.969	3.905	3.7	2520	3.969	3.905	4.5
	0.0003	266	3.953	3.889	3.7	2311	3.954	3.890	4.4

	0.0004	245	3.938	3.874	3.6	2114	3.938	3.874	4.4
	0.0005	211	3.923	3.860	3.6	1809	3.924	3.860	4.4
0.00006	0.00007	3208	3.953	3.889	4.5	27866	3.953	3.889	5.1
	0.00008	1419	3.941	3.877	4.3	12259	3.941	3.877	4.9
	0.00009	729	3.925	3.861	4.1	6254	3.925	3.862	4.7
	0.0001	445	3.911	3.847	3.9	3793	3.911	3.847	4.6
	0.0002	319	3.898	3.834	3.8	2703	3.898	3.834	4.5
	0.0003	297	3.882	3.819	3.7	2499	3.883	3.819	4.5
	0.0004	276	3.867	3.803	3.7	2305	3.867	3.803	4.4
	0.0005	242	3.852	3.789	3.6	2008	3.853	3.789	4.4
0.00007	0.00008	2970	3.870	3.806	4.5	24844	3.870	3.806	5.1
	0.00009	880	3.854	3.791	4.1	7309	3.854	3.791	4.8
	0.0001	596	3.840	3.776	4.0	4917	3.840	3.776	4.7
	0.0002	370	3.827	3.763	3.8	3034	3.827	3.763	4.5
	0.0003	308	3.812	3.748	3.7	2509	3.813	3.749	4.5

Table 1 (continued…)

SSAQL(p_1)	SSAOQL	n_σ	$k_{T\sigma}$	$k_{N\sigma}$	σ - Level	n_s	k_{Ts}	k_{Ns}	σ - Level
0.00007	0.0004	287	3.797	3.733	3.7	2321	3.797	3.733	4.4
	0.0005	253	3.782	3.718	3.7	2032	3.783	3.719	4.4
0.00008	0.00009	1665	3.784	3.720	4.3	13386	3.784	3.720	4.9
	0.0001	881	3.770	3.706	4.1	7035	3.770	3.706	4.8
	0.0002	387	3.756	3.693	3.8	3071	3.757	3.693	4.5
	0.0003	325	3.742	3.678	3.8	2562	3.742	3.678	4.5
	0.0004	304	3.726	3.662	3.8	2378	3.726	3.663	4.5
	0.0005	270	3.712	3.648	3.7	2098	3.712	3.648	4.4
0.00009	0.0001	2799	3.699	3.635	4.5	21618	3.699	3.635	5.1
	0.0002	1305	3.686	3.622	4.3	10016	3.686	3.622	4.9
	0.0003	443	3.671	3.607	3.9	3376	3.671	3.607	4.6
	0.0004	317	3.655	3.591	3.8	2398	3.655	3.592	4.5
	0.0005	281	3.640	3.577	3.7	2110	3.641	3.577	4.4

Table 2: $P_a(p_m)$ Values of known σ plans

SSAOQL	SSAQL (p_1)								
	0.00001	0.00002	0.00003	0.00004	0.00005	0.00006	0.00007	0.00008	0.00009
0.00002	0.91								
0.00003	0.88	0.95							
0.00004	0.87	0.94	0.95						

0.00005	0.85	0.92	0.92	0.93					
0.00006	0.81	0.88	0.89	0.89	0.90				
0.00007	0.80	0.87	0.87	0.88	0.88	0.89			
0.00008	0.66	0.73	0.74	0.74	0.75	0.76	0.76		
0.00009	0.64	0.71	0.72	0.72	0.73	0.73	0.74	0.75	
0.0001	0.62	0.69	0.70	0.70	0.71	0.72	0.72	0.73	0.74
0.0002	0.59	0.66	0.67	0.67	0.68	0.68	0.69	0.70	0.71
0.0003	0.58	0.65	0.65	0.66	0.67	0.67	0.68	0.69	0.70
0.0004		0.61	0.62	0.63	0.63	0.64	0.64	0.65	0.68
0.0005			0.60	0.61	0.62	0.62	0.63	0.64	0.65